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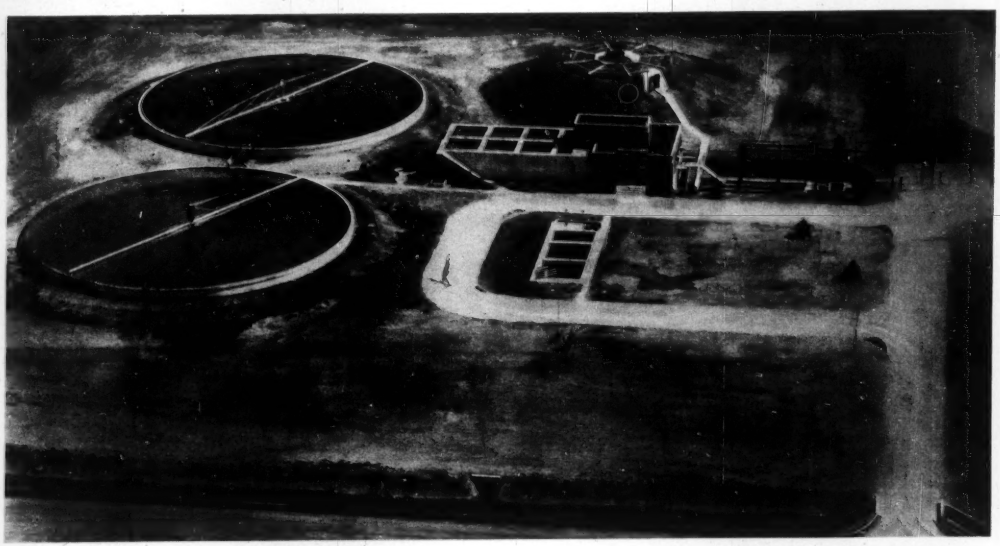

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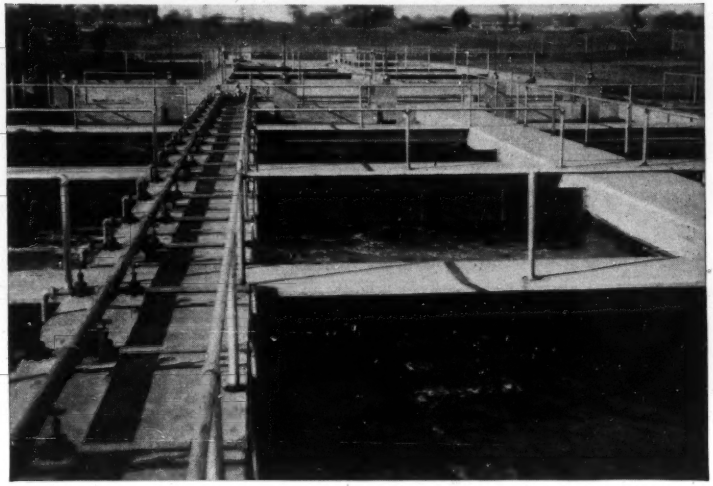

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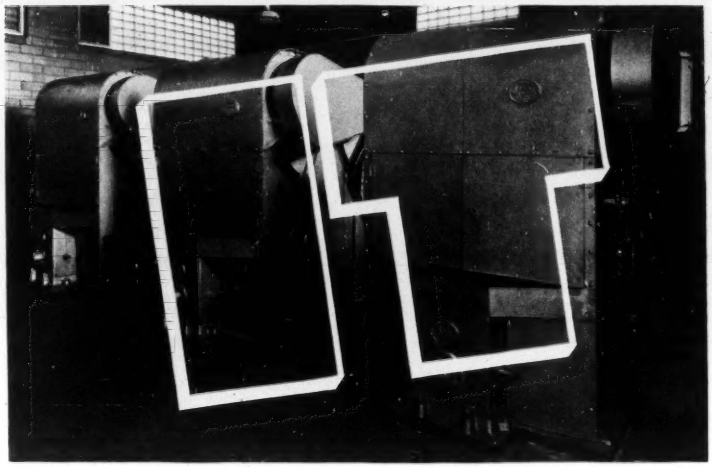

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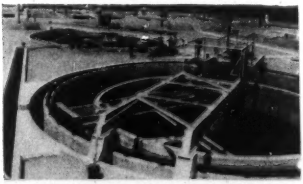

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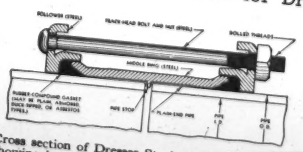

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Sewage Research

BIOLOGIC OXIDATION *

By Don E. Bloodgood

Superintendent of Sewage and Garbage Disposal, Indianapolis, Indiana

It has been found very helpful in the operation of the Indianapolis plant to continue with the daily "Biologic Oxidation" determinations on the activated sludge. The machine used in the work, as has been previously described (1), required for its construction, materials and equipment not readily obtainable in all sewage plants. With this thought in mind, my associate has developed a machine which can be constructed from parts readily purchased and that require a minimum of effort in their assembly (Fig. 1).

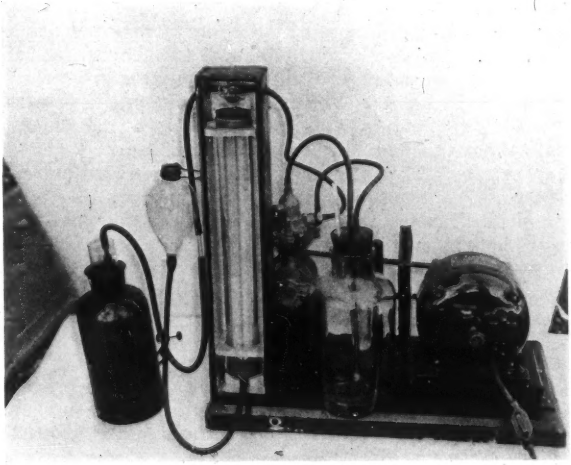

Fig. 1.

The Machine

A list of parts together with their approximate price is as follows:

1. 1/6 H.P. 1750 R.P.M. Electric Motor	$6.00
2. Paint spray pump (Sears and Roebuck No. 30K(3266))	3.50
3. 100 ml. gas analysis burette (measurement of oxygen used)	9.50
4. Thermometer 0°–100° C. (to obtain air temp. in machine)	1.00

* Presented at the Eleventh Annual Meeting of the Central States Sewage Works Association, Neenah-Menasha, Wis., Oct. 13, 1938.

5. 2000 ml. bottle (aeration bottle)	.70
6. 1 in. spherical diffuser	.35
7. 1000 ml. bottle (oxygen supply bottle)	.40
8. Rubber tubing, 6 feet, 3/16 in. I.D.	.60
9. Copper tubing, 3 feet, 1/4 in. O.D.	.15
10. Brass fitting (U14C Kerotest Half Union) or a T34A Tee and a 1/8 in. × 3/8 in. IPS bushing)	.17
11. Rubber stopper—No. 11 (aeration bottle)	.17
12. Rubber stopper—No. 6 (caustic chamber)	.05
13. Test Tube 38 × 300 mm. (oxygen supply bottle)	.40
14. Test Tube 29 × 200 mm. (caustic chamber)	.25
15. Test Tube 20 × 150 mm. (caustic chamber)	.06
16. Pulley, 1½ in. for motor	.15
17. Sheet metal for mounting, 2 sq. ft.	.15
18. Wooden base	.25
19. Glass tubing, 6 inches (caustic chamber)	.02
20. Leveling bulb, 150 ml.	.30
21. Machine stud bolt for blocking safety valve opening in pump	.01
Total	$24.18

Only slight alterations to a few of the parts as purchased are necessary and the extent of the changes is as follows:

The rubber fibre diaphragm of the pump is removed and replaced with a piece of lightweight automobile inner tube rubber, and the large washers on the diaphragm end of the connecting rod are removed, both changes resulting in a reduction in the amount of air pumped. The suction side of the pump is fitted with the brass fitting which must be filed to allow the rubber tubing to be fastened to it.

The spherical diffuser can be purchased or rounded out of a piece of porous plate. The connection to the copper air line is made by placing a piece of rubber tubing over the copper tube and forcing the two into the hole in the diffuser.

The gas burette shown is the most expensive part of the machine. A cheaper substitute for this is an ordinary 50 ml. burette and a three-way stop cock.

The test tubes listed have to be cut to the desired lengths in making the caustic chamber and the oxygen supply bottle.

It is believed that the construction of these machines has been so simplified that any one with a desire for information on the demand and activity of activated sludge, should not hesitate to attempt the construction of the machine.

All work previously reported has shown that the tests were made on runs of 15 minutes for the determination of the oxygen demand of the sludge and 90 minutes for the determination of the sludge activity. With readings on exactly 5-minute intervals, it requires the close attention of the operator for a period of 1.75 hours each day. In most cases it has been found that this is time well spent. If an operator is unable to devote so much time, it is suggested that the 90-minute period be cut to 15 minutes, thus obtaining the maximum oxygen requirement rate (sludge activity) and sacrificing the information on the character

of sludge, which is obtained from the interpretation of the 5-minute readings over the 90-minute period. Thus the total time, including that of taking the sample, running the solids, adjusting the solids to 0.50 per cent and making the test in the machine, should not exceed 45 minutes.

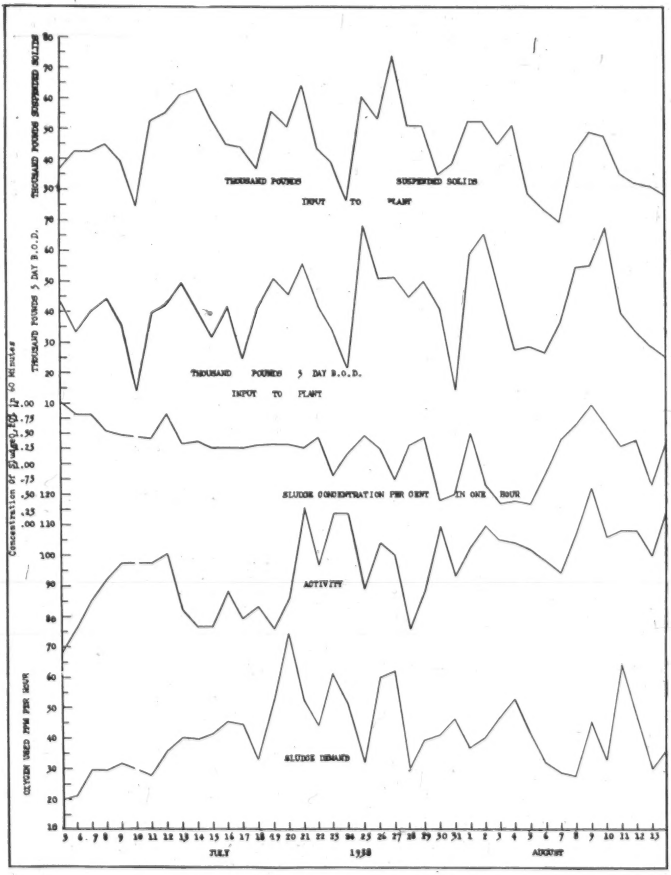

FIG. 2.

VALUE OF TEST

The sludge demand and activity are determined on each of the five separate divisions of the Indianapolis plant every day, seven days a

week. One instance of note when the test seemed of particular value will be cited. Perhaps a bit of background of the situation might be of assistance in visualizing what took place.

The additions to the activated sludge plant, first put into service in 1937, were designed to permit the entire plant to treat 50 m.g.d. and this flow was expected in 1950. The summer of 1937 saw a material increase over the flow of 1936. In fact, the average flow was 57.0 m.g.d. The mixed liquor solids in 1937 were held at approximately 2600 p.p.m. and much of the time a condition of over-aeration was experienced. At Indianapolis over-aeration brings about almost as many troubles as does under-aeration. So with the experience of the summer of 1937 at hand and not expecting a much greater flow in 1938, it was decided that the mixed liquor solids should be held at a concentration of about 2400 p.p.m. Before it could be realized, the sewage flow was averaging about 63 m.g.d. but it was still possible to carry on, though it meant running very close to a bulking condition.

Fig. 2 shows a period of operation from July 5 to August 18, 1938. The data shown were obtained on the No. 2 unit of the plant. It can be seen that with a daily B.O.D. load of not over 50,000 pounds, the sludge demand gradually increased, an indication that the sludge in this unit was being overloaded. It is possible that the difficulties encountered would not have been experienced if during the period of July 19 to August 10, the B.O.D. load had not materially increased or the mixed liquor solids had been increased. The struggle was carried on until August 3, when a severe bulking condition developed which lasted three days. The remedy was the reduction in B.O.D. load to this unit. The load was carefully watched by the sludge demand determinations, which showed an abrupt drop as soon as the load was reduced. As soon as the sludge demand began to drop, the activity began to decrease and this necessitated careful watch over the loadings so as not to lose the effectiveness of the sludge and permit it to become over-aerated, as it would have done had the loadings been regulated by the settling rate of the sludge. It is believed that the analysis of the results obtained show that they were telling the story and had they been interpreted properly, this difficulty in plant operation might have been avoided. It is hoped that during the summer of 1939 it will be possible to maintain a mixed liquor concentration that will handle the load delivered to the plant.

Industrial Wastes

Many times the plant has had the appearance of having received "a shot" of some industrial waste. Others have expressed the same opinion, to explain irregularities in the operation of their plant. In order to learn the effect of some of these wastes on activated sludge, certain wastes were added to activated sludge in the machine and the rates of oxygen utilization were obtained.

Previous work has shown that the quantity of oxygen required by

a sludge and sewage mixture decreases in proportion to the amount of sewage not yet absorbed by the sludge. Some of the wastes which have been talked about are milk, tomato and corn. Though these wastes are not believed to be particularly harmful to the Indianapolis plant, study has been devoted to them because it is known that some of them are received in appreciable quantities during certain seasons.

The milk used was pasteurized and skimmed. It was used in such concentrations as to give quantities of 5-day B.O.D. that might come within the same range as that of the peptone-dextrose synthetic sewage used in the regular determination of sludge activity. In the first test made, a quantity of milk was used which gave a 5-day B.O.D. of 226 p.p.m. when added to 900 c.c. of 0.50 per cent sludge. From the curve shown on Fig. 3, it can be seen that it required much less oxygen and

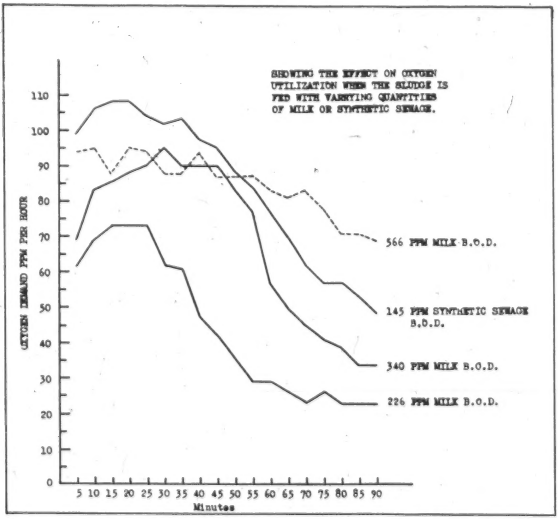

FIG. 3.

much less time to get the milk absorbed into the sludge than it did for the smaller quantity of B.O.D. in the synthetic sewage. By the addition of larger quantities of milk it was found that the sludge seemingly absorbed at least two and one-third times as much milk as it would synthetic sewage. The curve showing the oxygen consumption when 566 p.p.m. of B.O.D. was added is characteristic of sludge behavior when large loads are placed upon it. There was no indication that the milk had a harmful effect upon the sludge.

Tomato waste is largely composed of tomato pulp, so canned tomato juice was used in the tests. The amount of juice added was equivalent

to 115 p.p.m. of B.O.D. in 900 c.c. of 0.50 per cent sludge. The apparent rapid reduction in the rates of oxygen consumption was amazing. It was so rapid that it might have been easily believed that the tomato juice was harming the biologic life of the sludge, but this was disproved when a quantity of tomato juice, equivalent to 230 p.p.m. of B.O.D., was added to the same sludge and it was observed that the rates of oxygen immediately rose, but again quickly reduced and at a much more rapid rate than did a similar sludge handling the synthetic sewage. Fig. 4 indicates a more rapid absorption of tomato juice than of synthetic sewage.

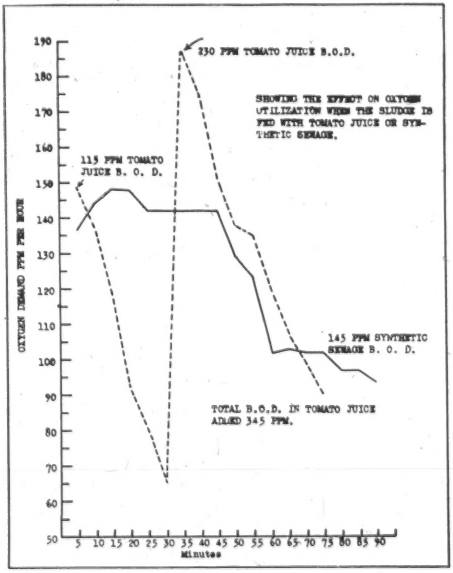

FIG. 4.

Corn juice or the waste from a plant packing whole kernel corn was used for the test. Though the oxygen requirements were not quite the same as for the tomato juice, the corn waste was somewhat similar in that it seemed to be readily absorbed by the sludge. After 85 minutes of aeration with the corn waste, the usual amount of synthetic sewage was added to the same sludge. The oxygen requirement immediately rose, indicating that the sludge still had the capacity to absorb more material. (Fig. 5.)

The results above reported do not mean that activated sludge cannot be damaged by the waste tested. It seems reasonable to expect, however, that if the wastes are not harmful to the absorbing mechanism

of the sludge they may be included in sewage in reasonable quantities. A "reasonable quantity" is the amount of organic matter that a given quantity of sludge can absorb, oxidize or convert. The amount can be determined by the use of the laboratory machine.

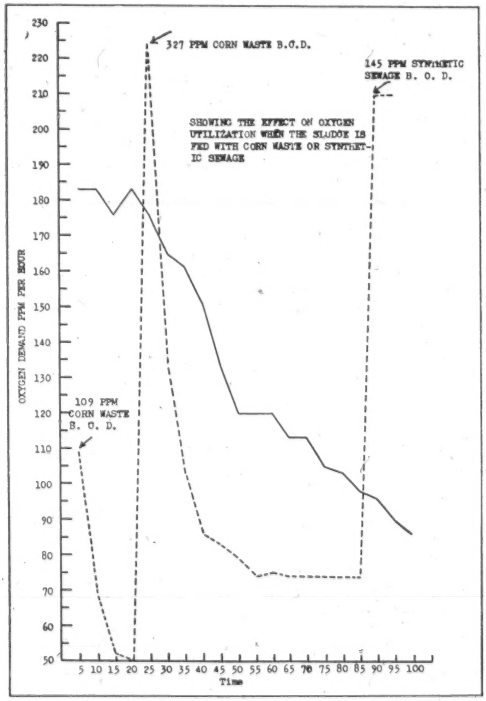

FIG. 5.

TRICKLING FILTER SLUDGE

The subject of rates of purification on trickling filters has been given considerable attention in the literature during the past few years. It was thought that some light might be thrown upon the matter if the sludges from the secondary settling tanks were examined for their oxygen absorbing rates and their activity measured in the same way as is done with activated sludge.

The most readily available sludge was from the trickling filter plant at Bloomington, Indiana. Though only a few runs were made with sludge from this plant, they were sufficient in number to indicate that there is a change in this sludge from day to day and that the sludge has

an oxygen demand and sludge activity that is comparable with some activated sludges. Changes in the character of the sludge at different times are presented by the curves in Fig. 6.

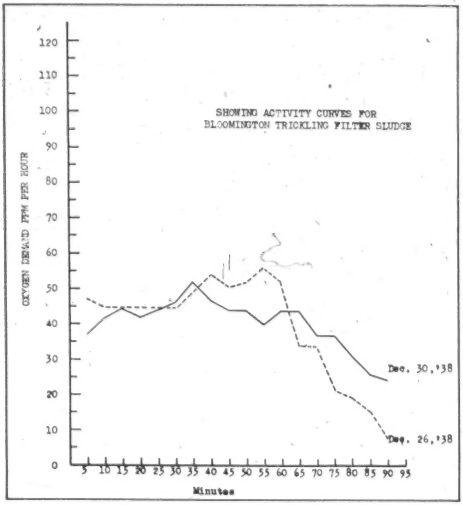

FIG. 6.

The writer does not feel qualified to make statements relative to the operation of trickling filters but he would like to ask a question which he hopes will be answered by some one who can find time to make extensive tests on trickling filter sludge for oxygen demand and sludge activity rates. If trickling filter sludge is similar to activated sludge, is it not possible to regulate the quantities of air through the filter and the quantities of biologic food to the masses of organisms on the stones and thus increase the efficiency of the filter? Such tests may show why some filters take higher rates and heavier loads than others.

CONCLUSIONS

1. A machine for obtaining oxygen demand and sludge activity figures can be easily made and at little cost.
2. A machine for obtaining oxygen demand and sludge activity data is indispensable for the operation of the Indianapolis Activated Sludge Plant.
3. The time taken to perform the tests is not prohibitive, considering the benefits obtained.
4. Milk, tomato juice, and corn waste are quickly absorbed by activated sludge.

5. Sludge from the secondary settling tanks of a trickling filter plant has sludge demands and activity rates not unlike activated sludge.

ACKNOWLEDGMENT

I wish to express my appreciation to my associate Mr. D. O. Bender for the work which he did in designing and assembling the simplified machine.

The various tests and determinations described in this paper have been made under the direction of Mr. P. W. Richards and his cooperation is duly appreciated.

REFERENCE

1. "Studies of Activated Sludge Oxidation at Indianapolis," *This Journal*, January, 1938.

A STUDY OF TRICKLING FILTER LOADINGS

By O. J. Knechtges

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During the past three years considerable data have been published on the performance of trickling filters. Available data are plotted in Figures 1 and 2 in terms of the B.O.D. applied and B.O.D. removed per acre-foot per day. "The B.O.D. removed" includes the reduction by final sedimentation, with the exception of Galesburg and possibly with the exception of Decatur. These data apply to trickling filters with dosing cycles and low daily dosages. The results shown in Figure 1 are for full-scale plants and those of Figure 2 are for experimental plants. The results for full-scale plants represent long time results—in most cases monthly and yearly averages.

The monthly results for Decatur without pre-aeration (Reference 8) have been computed from Table I and with a depth of filter stone of 5.7 feet as described in *Trans.* of A. S. C. E., 94, p. 544.

The yearly results for Decatur with the pre-aeration plant in operation have been computed from Tables V and VI of Reference 7, with a filter depth of 5.7 feet. These plotted results include removal by final sedimentation.

The monthly results for Fort Worth are computed from the data of Tables VI and VII of Reference 6 and for a filter depth of 9.0 feet as shown in " Metcalf and Eddy."

The data for the Ohio cities represent the average results of five years of operation, with the exception of one city, which had two years of operation. These data are shown in Table III of Reference 5.

The monthly results for Galesburg are calculated from the data of the Table on page 300 and from the description of trickling filters of Reference 4.

The data for Michigan were computed from the two tables and the description of the filters of Reference 3.

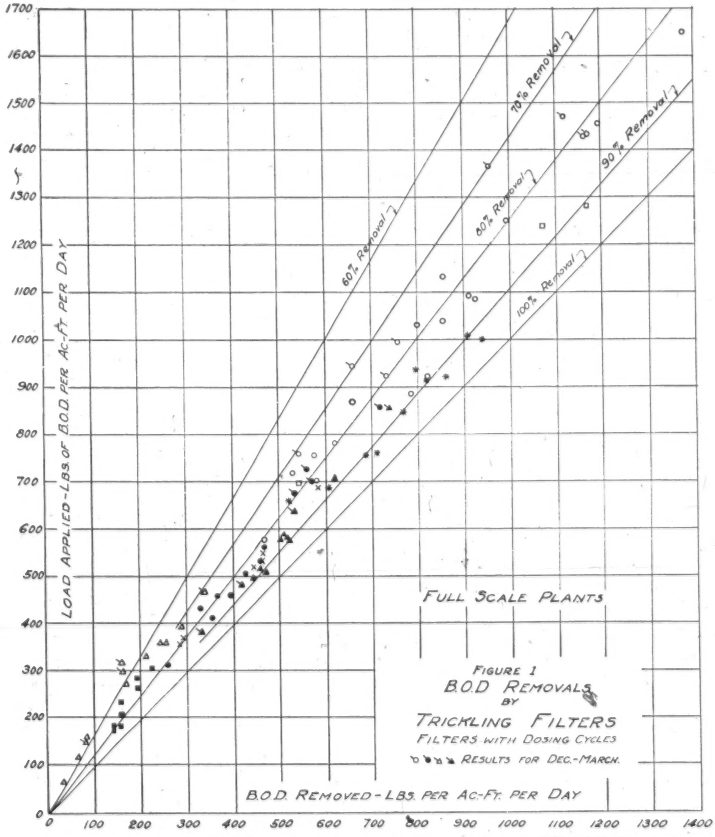
The monthly and maximum day results for Cedar Rapids have been obtained from Table VI of Reference 2; within any month the maximum removed may not occur on the same day the maximum loading had taken place; however, if the maxima had not occurred on the same day, the percentage removal would be higher for the day of highest B.O.D. removal. All published results for Cedar Rapids for the average month and for maximum day of loading approximate 80 per cent removal.

The monthly results for Iowa City are obtained from Tables I and II and from the description of filters of Reference 1. The percentage of B.O.D. removal for Iowa City was just about the same when the acre-feet in service were cut from 7.06 to 4.72 during the winter months, but the B.O.D. removed per acre-foot was increased considerably. This

indicates that probably the filters are lightly loaded when all filters are in operation.

Figure 2 represents the results of experimental plants and do not represent as long-time results as those in Figure 1.

The results for malt-house waste have been computed from Table



		Place	Reference	Waste	Dosage M.G.A.D.	Depth Feet	B.O.D. Applied P.P.M.	
1	●	Iowa City	S.W.J. X p 110	Domestic		6.83	159-230	
2	○	Cedar Rapids	S.W.J. IX p 659	Packing, Dom.	2.0 (app)	6.5	310 (app)	
3	□	Michigan	S.W.J. IX p 534	Milk	1.04	8.0	640-1180	
4	△	Galesburg	S.W.J. IX p 300	Domestic	2.78	6.0	42-147	
5	■	Ohio Cities	S.W.J. IX p 53	Domestic	2.0-4.3	7.0-10.0	108-274	
6	▲	Fort Worth	S.W.J. VIII p 506	Packing, Dom.	2.1-3.0	9.0	161-382	
7	×	Decatur	S.W.J. VI p 489	Starch, Dom.	2.9-3.4	5.7	75-139	
8	✱	Decatur	S.W.J. III p 175	Starch, Dom.	0.75-2.0	5.7	290-650	

III of Reference 9. The results for milk waste have been computed from the curve of Figure 7, Reference 10, at 20, 40, 60 and 80 cubic feet of rock per pound of B.O.D. The results for pea waste have been computed from Table I of Reference 11. The milk results have been computed from Paragraph 2 and the packinghouse result with an aerated filter has been computed from Paragraph 3 of Reference 4.

	Place	Reference	Waste	Dosage M.G.A.D.	Depth Ft.	Applied B.O.D.-P.P.M.	Reference
△	Wisconsin	S.W.J. VII p564	Malt House		8.0	250-490	9
○	Wisconsin	S.W.J. VI p580	Milk		8.0		10
×	Wisconsin	W.&S. 1934 p346	Peas	1.0-2.1	8.0	2350-4500	11
×				1.6-4.7	8.0	2200-4200	11
□	Iowa State	S.W.J. VIII p701	Milk	2.25	6.0	7/6 Oxy Con.	12
□			Packing	7.0	10.0	929	12

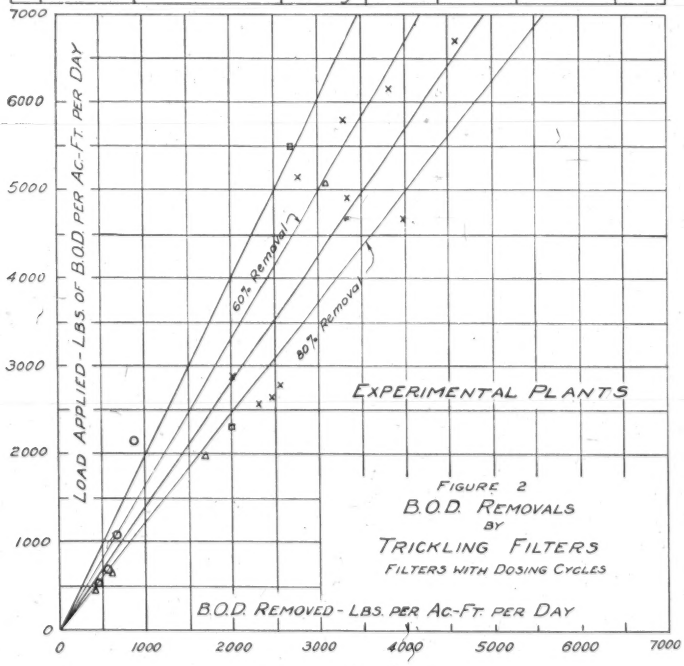


FIGURE 2
B.O.D. REMOVALS
BY
TRICKLING FILTERS
FILTERS WITH DOSING CYCLES

The plotted results of Figure 2 indicate that the percentage B.O.D. removal becomes less with higher loadings. The results of Cedar Rapids showed that 80 per cent removal can be obtained with maximum day loadings as high as 1650 pounds B.O.D. per acre-foot per day when the average monthly loading is 1132 pounds B.O.D. per acre-foot per day. These higher loadings have been successfully carried on trickling filters without ponding.

CHEMICAL COAGULATION OF SEWAGE*

X. EFFECT OF NON-SETTLEABLE SOLIDS ON THE COAGULANT DEMAND

By Harry W. Gehm

Assistant, Department Water and Sewage Research

In the operation of chemical treatment plants employing ferric salts for coagulation, wide variations in the dosage of chemical necessary during the day are commonly observed. This variation has been ascribed to many factors known to vary in sewage. The amount of suspended matter, particle size, presence of industrial waste, amino-ammonia nitrogen and general strength have been designated as the possible cause (1). Complete evidence in favor of any of these factors is lacking.

Observing plant operators have noted that during the day the demand is not correlated with the general strength as measured by the suspended solids and B.O.D. determinations (2). This does not mean that highly diluted night sewage does not have a lower coagulant demand than strong sewage. What it does mean is that a sewage containing 150 p.p.m. B.O.D. and 150 p.p.m. suspended solids may require more coagulant for clarification than one containing 300 p.p.m. B.O.D. and 300 p.p.m. suspended solids. It has also been observed that these variations exist where the sewage is of strictly domestic origin (3). This fact is definitely established by data presented, and while it does not mean that certain industrial wastes cannot raise or lower the coagulant demand, it indicates that wide variations do occur in normal domestic sewage and that these differences are not correlated with the strength in general.

In the third paper of this series (4) the effect of the settleable solids was discussed. It was found that this material did not influence to any appreciable extent the dosage of ferric iron salt required for clarification. In this paper an effort is made to determine what part, if any, the non-settleable solids play in determining the chemical demand.

The composition of the non-settleable solids is not so well known as that of the settleable solids. The source has been shown to be mainly feces and soaps. Some of these solids are probably similar to the coarse suspended solids in composition but in a finer state of division. The B.O.D. (5 day) per unit weight is much higher than that of settleable solids, but this may be due to the fact that the coarser materials are less available to the organisms during the five days of incubation employed, rather than because of a difference in composition. However, the carbon-nitrogen ratio is about 2 to 1, which, compared to the 9 to 1 ratio of the settleable solids, indicates a difference in composition. The ash content is lower, averaging about 10 per

* Jr. Series paper N. J. Agricultural Experiment Station, New Brunswick, N. J., Dept. Water & Sewage Research.

cent. The non-settleable content makes up about one-third of the B.O.D. of domestic sewage and about 40 per cent of the total suspended solids.

Method and Procedure

Turbidity and coagulant demand were determined on samples of thirteen domestic sewages of varied character, from which the settleable solids had been removed by sedimentation. Oxygen consumed was also determined on the settled sewages and their corresponding Seitz filtrates. The results were subtracted and the difference represented the oxygen consumed value of the dispersed fraction. On another series the oxidizable matter in this fraction was measured by the B.O.D.

In a second experiment, washed settleable solids were ground in a ball mill until a major portion was dispersed. Increasing portions of this dispersion were added to settled sewage of known coagulant demand. The mixtures were allowed to settle two hours to permit separation of settleable solids. Turbidity was then measured and coagulant demand determined.

Settled sewage (containing all the non-settleable fraction), cotton filtered sewage (coarser non-settleable solids removed), and paper filtered sewage (containing only particles under 7 microns in diameter) were used in this experiment. The fractions were all treated with ferric chloride in increasing quantities. Twenty-five p.p.m. $FeCl_3$ as iron was employed for treatment of all fractions of the sewages used, as this was found to give almost complete clarification. In preparing paper filtrates only small amounts were filtered through a single paper as porosity changed rapidly due to deposition of particles in the pores. In addition to the above work the turbidity and coagulant demand of ten filtered sewages were determined.

Results

In Tables I and II the data obtained in the first experiment are presented. Inspection of these tables shows no correlation between coagulant demand and non-settleable turbidity, or oxygen consumed and B.O.D. of the non-settleable matter. These figures, along with numerous plant observations not given here, led us to believe that the amount of non-settleable solids is no index of the coagulant requirements of sewage. The oxygen consumed determinations were made in order to see if the amount of organic matter alone might be the cause.

When a suspension of washed and milled fresh solids were added to sewage, substantial increases in non-settleable solids were observed but the amount of coagulant necessary was not increased. As evidenced by the data in Table III the added material was readily coagulated; for when a dose of $FeCl_3$ sufficient to give only partial clarification was added, all the suspended matter supplied in the form of milled solids was removed.

TABLE I.—*Coagulant Demand of Sewages Compared to Turbidity and Oxygen Consumed Value of Dispersed Matter*

Sewage	Ferric Iron Demand. P.p.m. $FeCl_3$ as Fe	Turbidity of Settled Sewage. P.p.m.	Oxygen Consumed of Non-settleable Solids. P.p.m.
New Brunswick	7.5	70	6
Plainfield	7.5	204	56
Plainfield	7.5	78	24
Hillsdale	10.0	106	29
Plainfield	10.0	190	49
Madison	10.0	204	39
Madison	12.0	200	30
Highland Park	20.0	125	33
Plainfield	20.0	55	14
Highland Park	25.0	190	36
Highland Park	28.0	212	39

TABLE II.—*Coagulant Demand of Sewage Compared to Turbidity and B.O.D. of Dispersed Matter*

Sewage	Ferric Iron Demand. P.p.m. $FeCl_3$ as Fe	Turbidity of Settled Sewage. P.p.m.	B.O.D. of Non-settleable Solids. P.p.m.
Highland Park	5	34	24
Highland Park	5	44	14
Plainfield	10	162	72
Princeton	10	63	64
Plainfield	15	170	60
Madison	15	128	70
Highland Park	12	55	73
Highland Park	25	136	40
Madison	30	220	98
Highland Park	35	120	60
Highland Park	35	200	50
Highland Park	50	178	73
Plainfield	55	232	29

TABLE III.—*Effect of Addition of Milled Solids on Coagulant Demand*

	Turbidity Settled Mixture	P.p.m. Turbidity Remaining		
		P.p.m. $FeCl_3$ as Fe		
		15	20	25
Morristown sewage				
1. Settled sewage	110	84	24	5
2. Settled sewage + milled solids	172	84	30	5
3. Settled sewage + milled solids	240	80	28	5
Plainfield sewage				
1. Settled sewage	178	94	38	20
2. Settled sewage + milled solids	220	93	40	24
3. Settled sewage + milled solids	260	90	44	20

The experiments in which settled sewage or cotton and paper filtrates were used were designed to determine if the quantity of any particular particle size range of the non-settleable fraction effected the coagulant demand. Table IV includes some data and from these

TABLE IV.—*Coagulant Demand of Filtered Fractions of Sewage*

25 P.p.m. of $FeCl_3$ as Iron Used	P.p.m. Turb. in Fraction		P.p.m. Turb. in Effluent	
Sewage sample	No. 1	No. 2	No. 1	No. 2
Settled	115	205	25	30
Cotton filtered	93	165	25	27
Paper filtered	61	93	24	34

figures it appears that neither the material removed by cotton or paper filtration was involved in determining the chemical dosage. There remained only the possibility that the finest particles, which pass through paper filters, determined the demand. Thus in Table V the

TABLE V.—*Turbidity of Paper Filtration of Sewage Compared to the Coagulant Demand*

Sewage Sample	Coagulant Demand. P.p.m. $FeCl_3$ as Fe	P.p.m. Turbidity. Paper Filtrate	Sewage Sample	Coagulant Demand. P.p.m. $FeCl_3$ as Fe	P.p.m. Turbidity. Paper Filtrate
1	5.0	68	6	20.0	31
2	7.5	35	7	20.0	19
3	10.0	28	8	25.0	51
4	10.0	59	9	30.0	27
5	15.0	42	10	45.0	33

turbidity of the paper filtrate of ten sewages, together with their respective iron demands, is listed. No correlation is observed between the sets of figures. It is unlikely, therefore, that any specific portion of the non-settleable fraction is involved. There remains, however, a possibility that only certain particles might be responsible.

Calcium soap suspended in distilled water was found to be readily coagulated merely by stirring. Small, compact granules formed on stirring 20 minutes; these rapidly settled when stirring ceased. Suspensions containing as much as 100 p.p.m. of calcium oleate reacted in this manner.

Sodium soaps reacted to the addition of small quantities of $FeCl_3$. Less than 5 p.p.m. of iron were sufficient to flocculate this material in amounts up to 100 p.p.m. The ease with which soaps coagulate on stirring probably accounts for the presence of granules along the sides of flocculators in sewage plants and part of the removal obtained by bio-flocculation processes.

Casein and the finely divided fecal matter acted in much the same

manner as did the soaps when suspended in distilled water. Plain stirring, or the addition of very small doses of $FeCl_3$, were sufficient to coagulate them thoroughly.

On addition of these same materials to sewage in doses of as high as 100 p.p.m. no increase in coagulant demand was found. In fact the floc formed was usually larger and settled better due to the weight of the added substance.

Discussion

Investigation has shown that, when dealing with pure colloids, the concentration of the iron salt necessary for coagulation increases with the amount of colloid dispersed in a medium of distilled water (5).

The non-settleable sewage solids exhibit many similar properties of a colloidal sol state, despite the fact that most of the particles are somewhat larger than true colloidal sol particles. Their larger size may be due to a high degree of hydration or partial natural coagulation (6, 7). They exhibit so many other qualities of true colloidal sols that in respect to many reactions they could be considered as such in our studies on chemical coagulation, on the basis of this assumption.

The amount of finely suspended material present in sewages was compared with the coagulant demand. If the dispersed matter acted as a colloidal sol some relationship should exist between the amounts of suspended matter and the coagulant dose necessary for coagulation. The existence of this relationship was doubted so measurements of the organic matter suspended in the sewage was included. Neither measurement showed any relationship to the chemical demand.

The greatest discrepancy in the data obtained seemed to be the fact that all the non-settleable solids were included in the measurement. Perhaps only the finer particles were involved. Experiments showed, however, that when all but the true sols (according to size) were removed, the coagulant demand remained the same as that of the whole sewage. This led to the conclusion that the particles larger than the true colloidal size had no influence on the demand.

The comparison of the turbidities of sewages from which everything but the soluble matter and the true sols were removed made it extremely doubtful if the suspended particles, or any part of them, affected appreciably the coagulant demand. This phase will be dealt with further in the next paper of this series.

When substances found in the non-settleable sewage in artificial suspension were subjected to the coagulant demand test, it was demonstrated that these materials were coagulated much more readily than the non-settleable sewage fraction. Even a suspension of feces coagulated much more readily. The variable composition of feces, however, must be appreciated in evaluating these results. Another discrepancy is the fact that none of these substances contained as high a percentage of nitrogen as was found in the non-settleable fraction of sewage. Duplication of anything as heterogeneous as sewage is impossible. However, these experiments showed that type substances,

when added artificially, were quite readily removed from sewage. The ready coagulability of the milled solids might well be recalled in this connection.

Summary and Conclusions

Experiments were performed to determine whether the non-settleable fraction of sewage was responsible for the amount of iron salt necessary to coagulate sewage. Coagulant demands were compared with the turbidity, oxygen consumed values and B.O.D. of the non-settleable matter. Similar comparisons were also made after all but the fines, resembling colloidal sols, plus the soluble matter, were removed by filtration. Washed and milled settleable solids were added to sewage to raise the amount of non-settleable matter, and coagulation tests were then made. Calcium and sodium soap, casein and a suspension of feces were tested in suspension in distilled water and sewage.

From these experiments it was concluded that:

1. No correlation exists between the amount of non-settleable matter in sewage and the quantity of ferric salt necessary for clarification.
2. Removal of the larger particles by paper filtration did not lower the dosage of iron salt necessary for clarification.
3. There was no correlation between the amount of colloidal matter (as based on size) and the coagulant demand.
4. Milled fresh solids added to sewage did not raise the demand. This indicated that mere physical form of sewage matter was not responsible for coagulant absorption.
5. Addition of very small quantities iron salt to suspensions of soaps, casein and feces clarified the suspensions readily. Addition of such suspensions to sewage did not raise the demand for clarifying chemical. It appears that such types of materials present in the non-settleable fraction of sewage are not involved.
6. Although not completely proven, it appears that the non-settleable solids present in domestic sewage account for little, if any, of the coagulant demand.

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Plant Operation

CONDITIONING AND SALE OF SLUDGE FOR FERTILIZER *

By William A. Allen

Superintendent, Pasadena Sewage Treatment Plant

Conditioning of sewage sludge for sale as fertilizer, as practiced at the Pasadena Tri-City Sewage Treatment Plant, developed as a matter of necessity. At the time the plant was constructed, relatively little information was available on satisfactory means of disposing of the surplus sludge from an activated sludge plant; in fact, it was considered one of the more or less unsolved and troublesome problems of this process of sewage treatment. The original plan for the plant was to dewater the surplus sludge to about 80 per cent moisture and deliver it to farm wagons equipped with manure spreaders. The equipment installed failed to give the results guaranteed, both as to capacity and moisture reduction, also, the nuisance created from spreading the wet sludge on the city-owned orange grove was such that there were numerous complaints on account of odors. After repeated attempts, and an equal number of failures by the manufacturers, to dewater the sludge in accordance with their guarantee, this method of sludge dewatering was discontinued. During the interim between the abandonment of the original dewatering equipment and the installation of vacuum filters the liquid sludge was run on the farm land and later was impounded in beds in the wash adjacent to the plant. Both of these methods had their attendant evils, such as odors and fly and mosquito breeding, and needless to say were the source of many complaints.

About December, 1924, two 11 ft. 6 in. by 14 ft. vacuum filters were installed, together with the necessary conveying equipment and bins for loading the filter cakes into trucks. A ditching machine was rented and kept in practically continuous use digging ditches for burying the sludge cake from the filters. After more than a year of this method of sludge disposal some of the disadvantages of burying sludge were apparent. After heavy rains the ditches filled with water, causing the sludge to come to the top and creating an odor nuisance which was readily and strongly objected to by residents in the vicinity of the plant. Storm waters coming into the wash caused erosion, which exposed the ends of many of the ditches, allowing the partially digested sludge to be carried down the wash and deposited along the bank for several miles, thus creating further odor nuisance. Placing brush on top of the ditches, before covering with dirt, was tried in an attempt to prevent the dirt from settling and allowing the sludge to come to the sur-

* Presented at the Fall Meeting of the California Sewage Works Association, Santa Barbara, Sept. 12–14, 1938.

face. This was only partially successful and due to continuing complaints a large crew of laborers under the supervision of a state inspector were required to re-cover the ditches where the sludge had worked to the top. It was estimated that more than 50,000 cubic yards of sludge cake was buried between January, 1925, and August, 1928, when burying was finally discontinued.

Mechanical drying equipment was installed in 1926 and 1927, the first test runs being made in February, 1927. From the start it was very evident that conditioning of the sludge prior to filtration was of vital importance. When burying sludge the moisture content of the filter cake made little difference, the object being to filter the sludge as economically as possible. When drying was started it was found that with a moisture content of 85 to 87 per cent in the feed to the dryer the results were very poor. Experience then, and since, indicates that the moisture of the dryer feed should not exceed 82 to 83 per cent. Lower water content is of course desirable, consistent with an economic balance between coagulant and fuel costs. When using sulfate of alumina as a coagulant, at a rate of 8 to 10 pounds per thousand gallons of liquid sludge, without filter aids, the average moisture content of the filter cake was 83 to 85 per cent. With a dosage of 10 pounds of sulfate of alumina and 10 pounds of filter aid (diatomaceous earth) per thousand gallons, a moisture content of 79 to 80 per cent was obtained. Up to the time the filter aid was added, part of the filter cake was dried and part buried, depending on the amount the dryer could handle. The addition of the filter aid enabled us to double the dryer output and eliminated the necessity of burying sludge. While the nitrogen value of the sludge was less with the use of a filter aid, due to dilution, the increase in dryer capacity and tonnage produced, and elimination of burying expense, more than offset this disadvantage, in fact, the cost per ton for the filter aid was less than the price received for the fertilizer and as long as this condition prevailed there seemed no reason for discontinuing its use. The use of ferric chloride as a coagulant, in place of sulfate of alumina, was started in June, 1930. It undoubtedly would have been used earlier had there been a dependable source of supply on the west coast at a reasonable cost. Results obtained with ferric chloride left no doubts as to its superiority as a coagulant; lower moisture filter cake was obtained with a very material decrease in the amount of filter aid used. The use of filter aid was discontinued in 1933, the point having been reached where it was no longer economical, and since that time ferric chloride only has been used for conditioning the sludge prior to filtration.

Several factors have been found of considerable importance in the conditioning and filtration of activated sludge; the time interval between dosing and delivery to the filters should be as short as possible; reaerated sludge requires less coagulant than sludge taken direct from the final settling tanks; suspended solids content of the sludge materi-

ally affects the amount of coagulant required, with a heavy sludge the filters can be speeded up, increasing the dry basis output per filter with a resultant lower cost for coagulant due to less water requiring conditioning. Normally our experience indicates that when the suspended solids in the sludge are between 5,000 and 7,000 p.p.m. approximately 200 pounds per ton, dry basis, of coagulant will be required. If the suspended solids are increased to 9,000 to 10,000 p.p.m., 7 to 8 per cent, or approximately 150 pounds, of coagulant per ton will be required. At times there are other conditions which affect the character of the sludge and result in an increase or decrease in the amount of coagulant required. Type of sewage treated, condition of sludge, method of coagulation and moisture content desired are factors which largely determine the amount of coagulant required.

Coagulation and filtration are but the first steps in our method of conditioning sludge for sale as fertilizer. The sludge must next be dried to about 5 per cent moisture, pulverized and screened to obtain as near as possible a uniform particle size for delivery to the sacking bins. The finished product, marketed under the brand name "Nitroganic," is packed in burlap bags containing 100 pounds net weight. Much has previously been written regarding sludge drying and the various difficulties experienced in odor elimination and dust problems and this subject will therefore be omitted here.

Various methods of marketing "Nitroganic" have been tried, such as contracting the entire output, selling direct to consumers and marketing through a limited number of distributors. The latter arrangement has been in effect for the past six years and has been found the most satisfactory. The Purchasing Agent for the City of Pasadena, who is also "Nitroganic" Sales Manager, supervises the activities of the distributors with regard to the sale of "Nitroganic." The retail selling price per ton is fixed by the city f.o.b. our warehouse and no deviation is permitted. The larger portion of our sludge is used by citrus growers, this being one of the largest agricultural activities in this part of the state and consequently the market for our fertilizer is considerably influenced by the citrus market. Users of "Nitroganic" are apparently well satisfied with results obtained, as much of our business is from growers who have used it year after year. We have many customers who have used our product since it was first made and continue to use it even during periods when our price is above the current market for organics. We find, however, that in general the consumer buys fertilizer on an analysis basis, and for this reason we endeavor to keep our price in line with other organics. "Nitroganic" is sold on a guaranteed analysis basis of 6.00 per cent nitrogen, 3.00 per cent phosphoric acid, total, and .30 per cent potash. The average nitrogen content of our fertilizer for the month of July, 1938, was 6.65 per cent, the minimum was 6.44 per cent and the maximum 6.86 per cent.

The following tabulation shows the fertilizer production, sales, revenue and cost per million gallons of sewage treated for sludge disposal for the past six years.

Sale of Sludge at Pasadena

Fiscal Year	Tons Fertilizer Produced	Tons Fertilizer Sold	Production and Sales Cost	Revenue	Net Cost Sludge Disposal	Cost per M.G. for Sludge Disposal
1932–33	3,169.80	3,848.00	$77,905.19	$40,891.65	$37,013.54	$14.12
1933–34	3,153.95	3,035.00	77,585.17	43,562.06	34,023.11	12.91
1934–35	3,025.60	2,880.45	78,411.52	54,321.25	24,090.27	9.02
1935–36	3,156.00	3,197.95	72,103.79	54,449.96	17,653.83	6.35
1936–37	3,396.50	3,512.75	69,671.23	69,723.36	(52.13)	(.02)
1937–38	3,492.05	2,819.20	76,669.81	62,730.42	13,939.39	4.51

It is of interest to know that for the fiscal year 1926–27, which was the last full year the filtered sludge was buried, the cost for sludge disposal was $54,304.19. The saving in cost for sludge disposal as now practiced leaves no doubt as to the merit of our present method of conditioning sludge for sale as fertilizer.

VACUUM FILTRATION OF SLUDGE*

By LeRoy W. Van Kleeck

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At the present time the vacuum filtration of raw or digested sludge is being employed or considered by a number of American cities. Genter [1] in a recent article states there are 170 vacuum filter units in use or being installed in 65 cities of the United States and Canada, of which 60 per cent were installed during 1937 and 84 per cent during the past three years.

A review of the American literature reveals that one of the earliest papers on the vacuum filtration of sludge (other than activated) was that by Keefer and Cromwell [2] in 1932 at which time they reported some laboratory results at Baltimore. Other papers giving the Baltimore laboratory work followed,[3, 4, 5, 6, 7, 8] and the profession of sanitary engineering is greatly indebted to Keefer, Cromwell, Kratz, Genter and the other workers at Baltimore whose studies helped greatly in making sludge filtration a practical reality for a variety of conditions.

Other papers of interest were those in 1934 by Jones [9] on the studies at Cleveland, by Edwards [10] who discussed both filtration and incineration, Donaldson [11] who presented one of the first papers on the practical operation of filters as applied at Hagerstown, Md., Ferguson and Wisely [12] who evaluated the costs of sludge disposal methods, and Mohlman's and Edwards' [13] paper which discussed various coagulants and conditioning methods.

In 1936 were published Bloodgood's [14] report on the laboratory filtration of Indianapolis activated sludge, Baumgartner's [15] comparison on the cost of iron salts, Fischer's [16, 17] discussion on the economics of various methods of sludge disposal, and Cameron's [18] excellent and practical paper on digested sludge filtration at Springfield, Ohio.

In 1937 Genter [19] contrasted coagulation with chemical precipitation in sludge filtration and in our current year, Messrs. Zack, Pitkin and Fedeler [20] released a joint paper describing the common commercial types of vacuum filters now in use.

It is the object of this paper to present the writer's experiences with the filtration of sewage sludges at sewage treatment plants in Connecticut. These plants are handling raw primary, raw chemically-precipitated, digested, and elutriated digested sludges. The subject matter has been divided into the following principal divisions: description of vacuum filters, the operation of filters, suggestions for future design of filters, a discussion on filter cloths and wire, preparation of the sludge for filtration, laboratory control, computation of filter

* Presented at the Joint Meeting of the New York State and the New England Sewage Works Associations, Hartford, Conn., Oct. 7, 1938.

yields, filter cake disposal, plant records, and a summary of operating data at Connecticut's vacuum filter installations.

Description of a Vacuum Filter

The modern vacuum filter is a rotary drum under vacuum, suspended in a trough which contains the conditioned sludge ready for filtration. The periphery of this drum is divided into a number of shallow compartments, each connected by individual pipes to the filter multiple valve. Each compartment is really an individual filter, being sealed from its neighbors by division strips, and functioning through its own pipe system as controlled by the filter valve.

The filter valve is the heart of the unit as it controls the filter cycle. The valve consists of a moving hub or pipe plate which revolves against a stationary valve cap also called the valve body. (See Fig. 1.) The hub rotates with the filter drum and contains a series

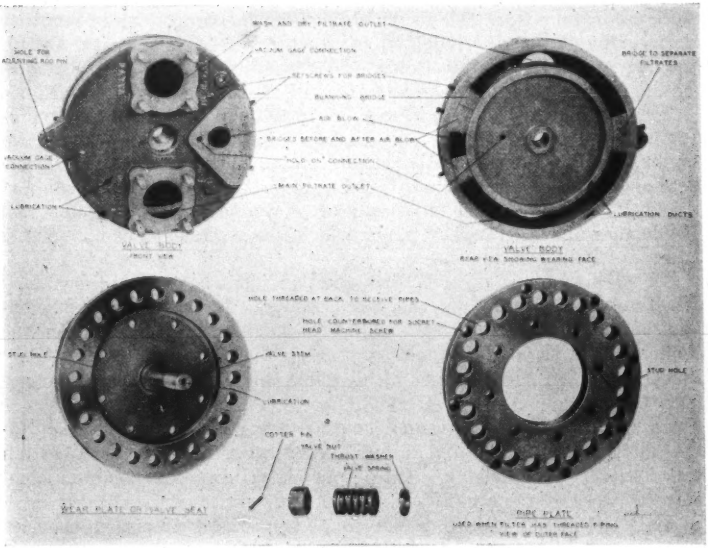

Fig. 1.*—Valve of vacuum filter.

of threaded holes to which are connected the pipes from the various filter compartments. As the filter revolves, each compartment is automatically subjected to the following cycle:

1. *No action* while the section still in the air submerges into the sludge vat. This part of the cycle is immediately after cake discharge.

* Courtesy of Oliver United Filters, Inc.

2. *Vacuum* after the section is fully submerged. In this step the cake is formed on the cloth.

3. *Vacuum* as the cake emerges from the vat and rotates in the air. Near the end of this phase air rushes through the cake assisting further in the drying and sweeping the water (filtrate) out of the filter piping.

4. *Air blow* at the point of cake discharge. Vacuum is cut off and air pressure applied to assist in discharge of the cake and cleaning of the cloth. (With the so-called string-type filter no air blow or scraper is used, cake discharge being accomplished by the lifting action of the strings.)

These steps are accomplished by suction operating through the valve cap (stationary valve body) as the individual pipe lines in the moving hub come into the recesses in the valve cap (Fig. 1). Liquor from the wet sludge (known as the filtrate) is drawn through the cloth, pipe lines and valve cap to a filtrate receiving tank, from whence it is continuously discharged by a filtrate pump, generally to the raw

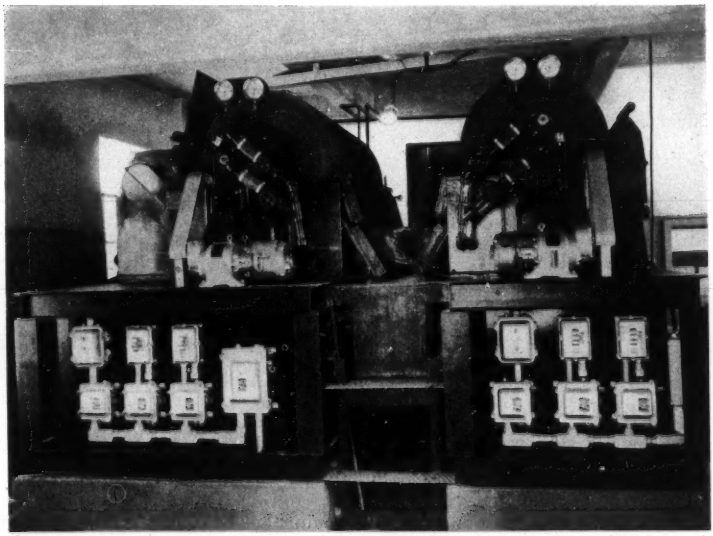

FIG. 2.—Twin filters at West Haven, Conn., showing common cake conveyor. Sludge conditioning tank is under the left unit.

sewage. The suction is created by a vacuum pump, and the air blow at the end of the cycle by an air compressor. The cycle is subject to variation by re-spacing of the bridges in the valve body, although the factory settings are generally satisfactory. Cycle variation on some filters is possible, without disassembling the valve, by an adjusting rod fastened to a lug on the valve body. (See Fig. 2.)

On the surface of the filter drum are supporting strips, usually of redwood or maple, a wire supporting screen and the filter cloth in successive layers. The cloth is held in place by spirally wound wire spaced about 1½ inches on centers across the face of the drum.

The filter drum is driven by a worm gear with variable speed drive. Vat agitators usually of the swing type, sometimes needed to prevent segregation of the sludge liquor and solids, are provided. A scraper or doctor consisting of an adjustable metal plate is set at the point of cake discharge to aid in this operation. Two vacuum gages are generally mounted on the filter, one indicating the vat vacuum; the other the drying vacuum near the top of the drum.

Operating a Vacuum Filter

It has been our experience in Connecticut that filters manufactured by reputable companies will perform successfully and with little mechanical regulation, *if* properly conditioned sludge is delivered to them. Sludge conditioning is of great importance. An operator with previous mechanical experience should have no fear of a vacuum filter and should manipulate one with ease.

The following steps in the operation of filters are listed here as a summary of good practice based on field experience:

1. Lubricate all parts at regular intervals, following the manufacturer's directions. Grease cups and oil wells should be checked every day. Give particular attention to the filter valve lubrication, as the efficiency of the filter is immediately affected if valve wear is permitted.
2. Most filters have wooden drums. After installation such filters should be rotated for several days in a vat of water. This will tighten the deck and prevent poor vacuum when starting filtration. For the same reason filters which are subject to idle periods should be turned over daily in a vat of water to prevent the wood from drying and vacuum leaks developing.
3. Prior to the introduction of conditioned sludge to the vat start the filter drum and turn on the wash-water spray (also called the "shower"). This soaks the filter cloth and helps to avoid cloth blinding by grease present in the sludge, especially when raw sludge is being filtered.
4. Drain off this wash water and close the drain valves.
5. With the filter drive off, admit conditioned sludge to the vat. Whether or not the vat agitators are started depends on the character of the sludge and the general conditioning set-up. At two plants in Connecticut, one filtering elutriated digested sludge and the other digested sludge, the operation of vat agitators immediately results in a thinner cake. However, at two other plants handling raw sludge the agitators are necessary to prevent marked segregation of the solids and sludge liquor. Sometimes intermittent operation of the agitators gives the best results. This is a point that every vacuum filter operator should check.

6. Start the filtrate pump, vacuum pump, and air compressor with both upper and lower filtrate valves closed. (See Figs. 2 or 3.) The upper valve regulates the vacuum during the drying cycle; the lower valve regulates the vat or cake formation cycle. With these valves

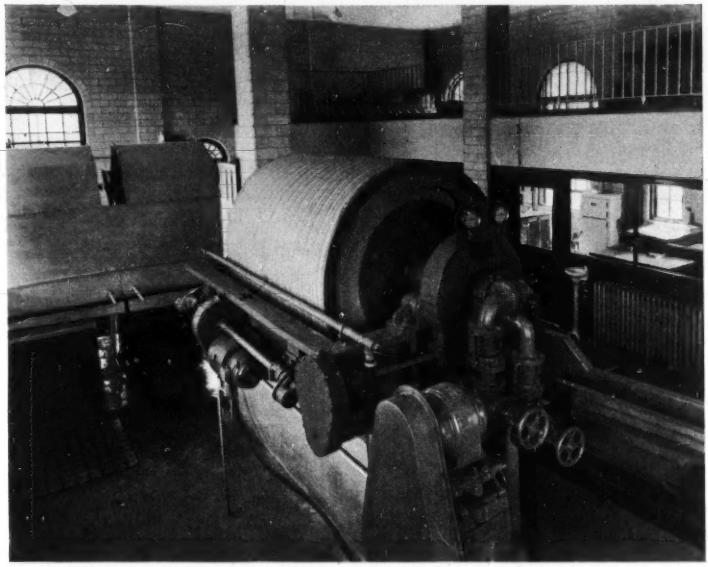

FIG. 3.—The vacuum filter at Middletown, Conn., showing shower, agitation drive, Reeve's control for drum speed, and the filter valve with appurtenances.

closed check the vacuum gage on the pump for leaks in the vacuum system. Most dry-vacuum pumps are set to deliver about 25 inches of vacuum, if the system is tight; the centrifugal type 20 inches. The vacuum should hold reasonably constant during operation, be about the same on both gages (the vat vacuum is generally slightly higher), and not show any appreciable variation from day to day.

7. Open the bottom filtrate valve wide and after a short interval start the filter drum drive. The interval is suggested to build up a cake on the emerging side of the drum for the first drum revolution. Another scheme is to start the drum drive immediately and let a section or two go by the scraper for resubmergence. Either method helps in the prevention of cloth blinding.

8. When the sludge cake on the drum reaches the top center of the revolution open the upper filtrate valve *slowly*. Watch *both* vacuum gages at this stage and do not allow the vacuum to drop excessively.

9. The compressed air valve should now be opened and the cake

scraper or doctor adjusted close to the drum. The air blow should start on each drum compartment just before it reaches the scraper and should continue until the whole of the section has passed under it. This insures that the underside of the cake is dislodged by the scraper across the whole of the section and a clean cloth results.

The air blow is generally set by the manufacturer for about 2 to 3 lbs. per sq. in. If water discharges with the cake, relief can generally be obtained by reducing the air pressure to 2 or even 1 lb. per sq. in. Dense cakes, such as elutriated sludge cakes, seem to give more trouble in this respect. With such a cake, air is not drawn through the filtrate piping at high enough velocities to sweep out the collected water. Filtrate piping and filtrate pumps must also be designed with adequate capacity to remove the water before the air blow cycle, or trouble will occur.

10. After the cake is discharging freely, unlock the scraper adjuster lever and re-set it to raise the scraper slightly from the wire. Cake discharge is then accomplished largely by gravity and wear on cloth, scraper edge and wire is avoided. (This step as well as No. 9 are omitted with string-type filters.)

11. After the cake is freely discharging there are very few mechanical adjustments needed. If the sludge has been properly conditioned the filter will automatically handle it without difficulty. The drum speed, which is adjustable, should generally be set for a moderately thin cake (¼ to ⅜ inch). Air is pulled through the thinner cakes more readily and this aids in the drying process. The thickness of cake can also be controlled by the depth of sludge in the vat as shallow submergence affords a shorter time for cake formation. Generally about one to one and one-half minutes submergence is desirable. Plants in Connecticut have found that better filtering results are obtained with fairly slow drum speeds, and most of the plants operate on the slowest speed. Excessive drum speed thins down the cake, yields are not, therefore, appreciably increased, and there is more danger of blinding the cloth.

12. When the run is over and the sludge level is so low the filter cake becomes too thin for good discharge, throw back the scraper and shut down, first, the vacuum, then the filtrate pumps. Turn on the water spray and open the drain valve in the vat. The purpose of the cleaning shower is to peel off particles of cake adhering to the drum. It is not intended to penetrate through the cloth. Adjust the shower pipe so that the jets of water will strike the drum a little above the point of tangency of a line drawn from the center of the pipe to the drum. Leave the air blow on during the washing period.

Considerations for Future Design of Vacuum Filter Installations

Cross-Connections.—The public health authorities of most states prohibit or recommend against cross-connections of any kind between potable and non-potable water supplies. Cross-connections include

any physical connection between the potable water piping and sewage or other filth. Small check or gate valves in the potable water supply line are not adequate protection, nor should differences in pressure be depended upon.

Potable water has been used with filters principally for supplying sealing water to vacuum and filtrate pumps or for sludge pipe flushing purposes. The first type of direct connection can be avoided through the use of a small float-operated elevated-tank supply and the second by temporary hose connections. Effluents from secondary treatment processes or filtrate water have been suggested for use in place of potable water, but the equipment manufacturers have in most cases been reluctant to recommend them. At one Connecticut plant, however, filtrate water has to date been successfully used as sealing water for the filtrate pumps.

Location of Exhausts.—Filter exhausts are audible for a short distance and some exhausts have an objectionable odor. The exhaust from raw sludge filtration is offensive; from digested sludge filtration much less so (a mild ammonia odor is the principal characteristic), and from elutriated digested sludge practically negligible. Depending, therefore, on the proximity of houses and the type of sludge being handled, filter exhausts should be located to avoid a nuisance.

The following disposition of exhausts has been made at plants in Connecticut:

1. A plant handling raw chemically-precipitated sludge has changed from an outlet to atmosphere at the side of the main operating building, where exhaust noise and odor were objectionable, to a surface-drain manhole some 100 feet from the main building. Noise is reduced and removed from the scene of activity and the odor can be detected only over the manhole.

2. A plant handling raw primary sludge has a submerged discharge to a pump well under the operating building. There is no noise or odor from the exhaust and no back-pressure trouble has been experienced with centrifugal vacuum pumps.

3. A plant handling elutriated digested sludge exhausts through a muffler to the roof of the filter operating building. No appreciable odor is detectable at the point of discharge and the exhaust is dissipated into the atmosphere above the working level. This appears to be a very satisfactory location for exhausts.

4. A plant handling digested primary sludge exhausts to atmosphere through a pipe discharge at head level at the rear of the filter building. A local noise and ammonia odor are present but there is no nuisance. Exhaust to the roof would have been better.

Sludge Feed Lines.—The feed lines from the sludge conditioning tanks to the filters should be at least 6 inches in diameter, preferably 8 inches or even larger. These minimums should apply regardless of the sludge head, length of pipe or type of sludge. Plants using 3 and

4-inch pipes have had clogging troubles and the feed is frequently too slow to keep the filter vats at the proper operating level.

Filter Vat Drains.—Filter vats should be provided with individual drains which do not empty into the sludge conditioning tanks. A return to digestion tanks, the raw sewage, or sludge concentration tanks should be made so that a vat can be drained, the cloth washed and filtering operations resumed without upsetting the sludge conditioning process. The drains should not be less than 4 inches in diameter.

Sampling Points.—Designers should provide sampling points for unconditioned sludge and the filtrate. The conditioned sludge can be sampled, when necessary, directly from the filter vat.

Protection of Vacuum Pumps.—Vacuum pumps, especially the so-called dry-vacuum type, should be protected against the entrance of filtrate. This type is a reciprocating unit and any appreciable liquor in the chambers may readily cause failure of the pump. The pounding sound accompanying this condition cannot be relied upon as sometimes the damage has been done, or the noise is not observed. The centrifugal type is less subject to damage by filtrate but should nonethe-less be protected. On some installations vacuum breakers, operated either on the pop valve principle or by a float-controlled device set in the filtrate receiver, have been installed to reduce the vacuum on the filter drum whenever the filtrate accumulates to a dangerous depth in the filtrate receiver. (The filtrate receiver is a tank from which the filtrate pump removes the filtrate to a point of discharge, usually the raw sewage). These breakers are a safety precaution but subject the filters under some conditions to varying vacuums with some detriment to efficiency. The best arrangement is a barometric leg of about 30 to 32 feet at which height the vacuum pumps pull their vacuums. Any possibility of moisture other than that in the air or in occasional foam, reaching the pumps, is thereby prevented. This requires in most cases a vacuum tank located near the roof of the operating building, but the filtrate receiver can still be situated on the operating floor.

Control of Sludge Feed.—Pumps or bucket elevators for delivering unconditioned sludge to conditioning tanks or the same equipment for delivering conditioned sludge to the filter vats should be specified for a *wide* range of capacity, otherwise it is difficult to maintain the filter vat level. Gravity flow of conditioned sludge to the filters is strongly recommended.

With gravity flow, the filter feed can be controlled by weir or float settings at the conditioning tanks. There are many installations where the use of a float at the conditioning tank or filter vat would seem desirable to prevent conditioned sludge from discharging to the vat overflow pipe. If such sludge is returned to the conditioned sludge over-agitation is likely, if returned for conditioning an over-dose of chemical may occur, or if returned to concentration or digestion tanks the conditioning chemicals have been largely wasted.

Valves.—Valves on sludge piping used in connection with filters

should be of the *full* opening type. Plug valves and the like have given trouble.

Reduction of Noise.—For the larger installations where vacuum pumps, air compressors and filtrate pumps are driven by individual motors, this equipment might preferably be located in the basement apart from the filters proper. This results in less noise on the operating floor and incidentally provides additional height for the barometric leg previously recommended.

Odor Control.—Unless the sludge is elutriated, filter room exhaust fans are desirable adjuncts for odor control.

Cake Conveyors.—The details of the filter cake belt or mechanical elevator for cake conveyance deserve more attention than has usually been given. Higher sides are needed to prevent spillage on the floor; excessive slopes should be avoided to prevent the cake from rolling into balls; when storage hoppers are provided the discharge should be well into the center of the hopper and not on the edge, otherwise much manual handling results. Likewise steep hopper sides and large bottom openings are necessary if cake sticking is to be minimized.

When sludge incinerators are used for final disposal of filter cake, a belt by-pass to the outside of the building should be included in the design, so that filter cake may be carted away in trucks during repairs or other interruptions in incineration. Some thought should also be given to manual removal of the cake at the filters if the mechanical conveyor fails.

Safety Features.—The construction and installation of vacuum filters should include a consideration of safety features. Several physical injuries have occurred at vacuum filter plants. The filter space should be ample—avoid crowding. On elevated filters handrails, non-slip treads and properly spaced steps should be given the consideration they deserve. There should be ample lighting, both natural and artificial. The inspecting of the conditioned sludge, operation of the washing shower and other routine duties of the filter operator should not require the abilities of an acrobat. Operators should avoid direct contact with the sludge as much as possible. Hands should be carefully washed with hot water before eating and prompt first aid instituted for all skin breaks. The prevention of infections at sewage treatment plants has been discussed by the writer in a recent paper.[21]

A Discussion on Filter Cloths and Wire

Filter Cloths.—The filter medium should be chosen for the type of sludge being filtered and the severity of service. One of the leading cloth houses lists eight grades of cloth for sludge work. These include cotton cloths with and without nap, wool cloths, monel metal cloth, and glass cloth.

When purchasing filter cloths observe particularly the strength of the warp thread. The strength of the warp varies with the amount of

twist, pull, etc., and is some indication of the life expectancy. Napped cloth is produced with spiked rollers to loosen the fibers bound in weaving and some operators feel with certain sludges that this nap retards plugging of the weave. It appears that unbleached cotton cloth should be used as the oil should be of some benefit in repelling water and hence grease, carbonates, and other solid constituents that tend to blind the weave.

The life of filter cloth varies with its use, the kind of sludge filtered, the presence of industrial wastes, the amount and kind of conditioning chemicals required, and the maintenance given the material. As the cloth ages, increasing amounts of chemicals are required for conditioning, so that a point is reached where it is more economical to change cloths.

Raw sludge, for example, frequently contains grease in a form that quickly clogs the weave, necessitating frequent washings with soap. An industrial waste that will quickly blind a filter cloth, when present in raw sludge filtration, is waste crank-case oil or the greasy wastes from dry-cleaning operations. Any appreciable amount of such wastes requires a complete suspension of operations and a cleaning of the cloth with Oakite or soap. Strong acids or alkalies present in raw sludge will also affect cloths.

Lime, when used for sludge conditioning, may deposit insoluble carbonates in the cloth, causing incrustation. In such cases acid washing of the cloth should eventually be done, this in turn shortening the cloth's life. Likewise an excess of ferric chloride will cause precipitates of iron on the cloth and shorten its service.

The maintenance of filter cloth is a subject on which operators are not in full agreement. Some do very little; others fuss continually with soap solutions, acid washings and mechanical adjustments. Generally there is a middle common-sense course which should be followed for best results. The following suggestions on maintenance are made with the hope of stimulating interest on the care of cloths and with the expectation that certain comments will have practical application at a given plant:

1. Remember step 10 under instructions for operating a filter. Proper adjustment of the scraper will lengthen cloth life. Inspect the scraper edge at regular intervals. If worn unevenly it should be filed to an even finish. This will maintain the original angle and shape. If the scraper edge becomes uneven the cloth is subject to tears, which ruin the material, cause a cloudy filtrate, and require time to repair. Occasionally the scraper edge may become too sharp and it should then be filed to a blunter edge.

2. Protect the cloth from the hot summer sun.

3. Protect the cloth from mildew. At a Connecticut plant recently filters which had been idle for a few days developed a mildew on practically new woolen cloths. This mildew developed on the drum sections submerged in the vats where some moisture is generally present.

Spraying with formaldehyde is said to arrest this trouble but keeping the cloths wet as a prevention is the better scheme. If the idle cloths are allowed to dry thoroughly the decks may shrink allowing vacuum leaks to develop. Keeping the decks wet prevents this latter trouble, and it is not likely that cloths kept moist will mildew. It is probably a half-way condition that causes trouble. In order to keep the cloths wet the drums may need to be rotated in water or the shower spray used several times daily.

4. Avoid over-conditioned sludge. Not only might such sludge filter poorly but cloth incrustation from either excess iron or carbonates will result.

5. Wash the cloth thoroughly with the shower after filtering. Keep on the air blow.

6. When the cloth becomes greasy, sponge or lightly brush it with a mild soap solution, such as Lux or Ivory, using fairly warm water. Oakite, used half the standard package to a pail of water, is also very good. These remove the grease and soften the weave. A soft bristle brush can be used for applying the solutions and for bringing up the nap in napped cloths.

7. When lime is used for conditioning, an acid bath is desirable for the cloth as its age increases. A mild acid wash followed by thorough wetting with water will remove considerable of the deposited carbonates in the cloth. For this purpose commercial hydrochloric acid (HCl) is used.

If the acid is diluted 1 quart to 12 quarts of water (pour the acid on the water) a solution of approximately 2½ per cent results which should not excessively attack the average cloth. For delicate cloth dilute about 1:30. Do not spill the acid on the clothes or paint, and wear rubber gloves when applying. A soft brush may be used for application.

There is a filter cloth cleaning fluid on the market known as "Hibitite," or "Inhibited muriatic acid." This is claimed to remove the deposits in the cloth efficiently without attacking the fabric.

8. A whistling sound, cloudy filtrate or loss of vacuum indicates a hole or holes in the cloth. These holes can be patched until the cloth is either too patchy for use or otherwise rendered unserviceable by chemicals, grease or sludge solids.

Filter Wire.—Steel or bronze wire is used in Connecticut. One plant handling raw sludge uses No. 12 steel wire, discarding the wire each time a cloth is changed. The average time for changing a cloth on filters 3 ft. by 6 ft. is 2½ hours for two men. Scrubbing of the metal supporting mesh is not usually necessary. Another plant also filtering raw sludge uses No. 14 gage bronze wire. The wire is used for two cloths. At this plant, with filters 8 ft. by 8 ft., a full day is required for two men to change a cover. The additional time is needed not so much because of the greater filter area as the necessity for thorough scrubbing of the supporting mesh screen, and the incon-

venient facilities for feeding the wire on the cloths. Manufacturers of filters should give thought to this operation. Wire-feeding devices are becoming standard equipment with many modern filters.

Sludge Conditioning

The proper conditioning of the sludge, as has been already mentioned, is by far the most important step in the process of sludge filtration.

Freshness of the Sludge.—When raw primary or raw chemically-precipitated sludge is filtered, freshness is important. Stale raw sludge requires additional conditioning chemicals and is sometimes extremely difficult to filter regardless of the amount of chemicals employed. These septic troubles will be encountered primarily during the summer, or at times when for one reason or another the settling tanks are not cleaned of their daily sludge accumulation.

When sludge filtration is under consideration the character of the summer sewage should be investigated and if septic solids are a probability either digestion, elutriation, or both appear very desirable in view of operating experience. Not only do septic raw sludges exhibit poor filtering characteristics and high chemical demands but odors are greatly intensified and may readily become a nuisance if the plant is located in a residential area. Pre-chlorination of the raw sewage is of decided help in reducing odors and improving filtering characteristics.

Dry Solids in Sludge.—Sludge which is too low in solids is difficult to filter. A solids content of 6 to 8 per cent for raw sludge seems to be a reasonable expectancy under average conditions.

In the case of digested sludge experience at one Connecticut plant seems to confirm the reports of Cameron.[18] At Springfield, Cameron states the more completely the sludge is digested the better are the results. The lowest chemical costs are obtained at a solids content of about 17 per cent. The range from 14.5 to 17.5 per cent solids he states gives best filtering.

At Middletown, Connecticut (Fig. 3) a digested sludge ranging from 14 to 18 per cent solids, of which only 32 to 35 per cent are volatile, produces an excellent filter cake using about 2.5 per cent ferric chloride and 6 per cent calcium oxide (CaO), (dry basis). It is interesting to report, however, that sludge with 20 per cent solids has been obtained at this plant and cannot be filtered, regardless of the chemical additions, unless the sludge is first diluted with water. A 15 per cent sludge seems to be ideal.

Industrial Wastes in Sludge.—The deleterious effects of grease and oil in raw sludge have been pointed out in connection with filter cloths. Any industrial waste in sludge may affect filtration, possibly advantageously.

Elutriation of Sludge.—Elutriation or sludge washing has been fully discussed in the literature [1, 5, 6, 7, 19] and a description of the proc-

ess will not be repeated here. Elutriation is of decided benefit in filtering stale raw sludge or partially digested sludge. A number of Buchner funnel tests with various sludges in Connecticut have confirmed this. One of the advantages of elutriation is the elimination of lime as a conditioner. This simplifies chemical conditioning, eliminates the ammonia odor, and saves the cost of an additional conditioner. Against this saving must be balanced the installation cost of elutriation and its operating costs.

The sludge floc produced by ferric chloride alone is unstable and both laboratory and plant results indicate that such sludge should be filtered immediately (continuous feed and not batch) and particular care taken that the floc is not broken up before reaching the filter vat. Gravity flow of the conditioned sludge is recommended.

At Hartford, Connecticut, where elutriation of sludge is being employed, limited experience to date indicates a ferric chloride demand of about 1.75 per cent for a 14 per cent solids sludge, of which about 30 per cent is volatile (see Fig. 4). Counter-elutriation, using a 1:3 mix

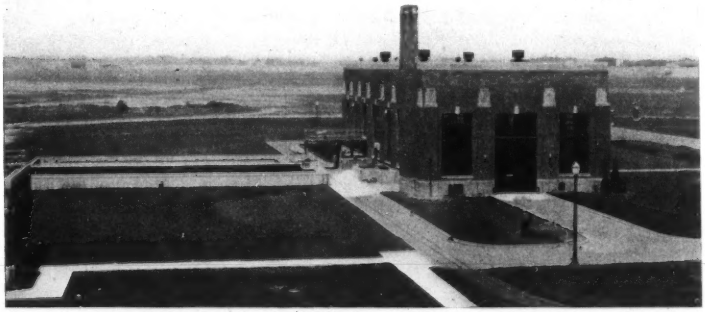

FIG. 4.—The sludge filtration building at Hartford, Conn. The sludge elutriation tanks are in the rear.

with well water, is being used at present. The elutriate to date has contained less B.O.D. and suspended solids than the raw sewage. The atmosphere in the filter building is remarkably free of odor, nor are any carrying odors emanating from the open elutriation tanks. A local gas odor much like the odor present when drawing digested sludge to sludge beds is detectable directly over the first mixing tank. The odor over the tanks used for settling the elutriated sludge is very slight. The settling tanks, as well as the mixing tanks, could be covered to reduce further the possibility of odor in populous areas.

When digested sludge is not elutriated, lime is generally used with ferric chloride for conditioning. The ammonia odor noted in filtering such sludge is largely the result of the reaction:

$$NH_4HCO_3 + Ca(OH)_2 = NH_4OH + CaCO_3 + H_2O$$

The ammonium bicarbonate is naturally present in sludge and the ammonium hydroxide accounts for the ammonia odor. The calcium carbonate is a contributing factor in the plugging of the filter cloth.

Concentration Tanks for Sludge.—Concentration tanks are desirable adjuncts to sludge filtration. The dry solids in fresh raw sludge can generally be concentrated an additional 1 or 2 per cent in such tanks. Digested sludge has run so heavy at Connecticut plants that additional concentration has not been necessary. Occasionally concentration tanks have been utilized to dilute heavy sludges with water.

Cylindrical deep tanks are preferable to square or rectangular ones. They should have multiple draw-offs at about 1.5 foot intervals. Facilities for flushing with water or sewage are desirable.

If sludge from plain-settling or sludge digestion tanks is pumped into a concentration tank some compacting of the sludge occurs, and a more uniform sludge is also secured for conditioning. Generally 2 to 4 hours settling in such tanks allows for as much concentration of the solids as is reasonably practical.

In batch-mix plants the sludge conditioning (mixing) tanks can also be utilized as concentration tanks. This has proven practical. When filtering raw sludge at least two concentration tanks should be provided. Although some sludge can usually be filtered directly from the settling tanks, as the sludge level lowers, concentration is desirable to obtain a uniform sludge of ample solids content. When the solids in the sludge drop below 5 per cent the formation of a cake on the drums becomes increasingly difficult.

Sludge should not be held too long in concentration tanks, especially in summer, or septic material, difficult to filter, will develop. The tanks will also "work" and little or no supernatant can be removed under such conditions.

Design and Operation of Mixing Tanks.—Mixing tanks for sludge conditioning are either of the continuous-flow or batch-mix type. The former is generally used at the larger plants. The batch type gives more accurate control of the amount of chemicals used for conditioning and the time of mixing, but the method requires more operating attention, is therefore slower, and is subject to certain filtration limitations. Chief of these limitations is the breaking down of the floc as the sludge is held. Our field experience has been that raw sludge breaks down much faster than digested. This confirms laboratory work. The maximum holding time at a batch-mix raw sludge plant is 1½ hours, beyond which filtering is markedly affected. Every effort is made at this plant to filter a 600 to 700 gallon batch in one hour or less. Usually 45 minutes is required. The permissible holding time at a digested sludge plant has been, however, about five hours.

At both plants the conditioned sludge has been subjected to additional agitation, after conditioning, which is undesirable. One uses a bucket-elevator, which not only moves through the conditioning tank, thus disturbing the prepared sludge, but also returns a portion of the

sludge to the tank. The buckets on bucket elevators should discharge their entire contents to the filter feed lines. The other plant pumps the sludge to the filter vat with some overflow of sludge returning to the mixing tank. This overflow has been reduced in recent operation by manual control of the pump, as the agitation resulting from this return was destroying the floc.

As previously pointed out, gravity flow float-controlled sludge feed is urged by the writer to reduce to an absolute minimum the disturbance of sludge that has once been conditioned. If a pump must be employed, a plunger-type, not centrifugal, should be used and its operation controlled with a float in the sludge vat. Bucket elevators, if used, should move slowly through the sludge and the entire bucket contents should be discharged. *These points are important.*

Tanks of protected metal or concrete are giving good service and have during a period of 1 to 2 years shown no excessive corrosion. Ferric chloride solution is not, of course, admitted to them until the sludge is also present. Batch-mix tanks might preferably be circular in shape and have conical bottoms to prevent sludge and chemicals from accumulating around the sides. Considerable residue of sludge and chemicals will collect in the corners of square tanks.

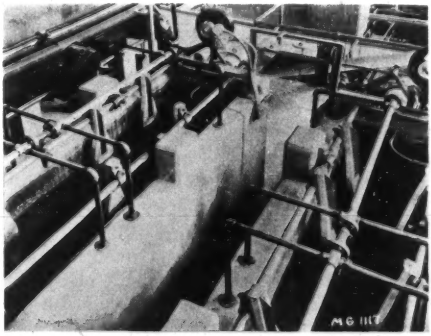

FIG. 5.—The sludge conditioning tanks at Hartford, Conn. The belt conveyor and cake weight recorder show in the right background.

It appears that mechanical agitation is superior to compressed air for mixing. Air tubes or plates clog easily and are troublesome to clean. Air is lazy. It escapes at the point of application in large bubbles with ineffective mixing, whereas mechanical mixers move effectively through the sludge. The plants using air in Connecticut are dissatisfied with the results and intend to install mechanical mixing. At present the sludge mixing at these plants is erratic and Buchner funnel tests have shown that filtering troubles are frequently due to improper mixing.

Of course, mechanical agitation may also be poor. Violent

whipping of the sludge must be avoided. Speed adjustment, avoidance of short-circuiting, and prevention of corrosion to the mixing paddles are among the things that should be considered. Figure 5 showing the sludge conditioning tanks at Hartford, Connecticut, as designed by W. A. D. Wurts, assistant city engineer, embodies these points admirably and is worthy of careful study. The action of the wooden paddles (no metal comes in contact with ferric chloride) causes the chemically conditioned sludge to be carried between approaching blades, insuring good mixing without undue agitation of the forming floc.

Chemicals for Conditioning.—Ferric chloride is being used at all vacuum filter plants in actual operation in Connecticut and is proposed for use in plants under construction. At most of the plants in operation the anhydrous (98 per cent) ferric chloride is purchased in 150 lb. non-returnable drums. One plant originally planned on the anhydrous form, but a present favorable price on lump chloride (60 per cent ferric chloride) has resulted in the latter's use. Lump chloride is somewhat more troublesome to dissolve and more bulk must be handled for an equivalent amount of available ferric chloride. It is shipped in barrels holding approximately 500 lbs. Liquid ferric chloride has not been used primarily because railroad sidings are not available. The cost of hauling and storing the liquid would be greater than the present handling charges for the dry form.

Ferric chloride is first prepared as a solution at all plants before adding it to the sludge. At one, a sodium-silicate-lined tank containing air plates is used for mixing, from which tank the solution discharges by gravity to a rubber-lined tank in series, with an adjustable displacement type feeder. An orifice feeder was removed at this installation because of clogging and corrosion trouble. Other feeding methods include:

(*a*) Rubber-lined square tanks with false-bottom wooden boxes suspended at the center for dissolving the chemical. Mixing is accomplished by hand with paddles. Chemical feed is by direct drawdown for batch mixing or by displacement feeders for continuous-mix set-ups. Additional control is effected at one continuous-mix plant by a float-level control in the conditioning tanks. This float proportions both the ferric chloride feed and sludge feed depending on the level.

(*b*) The chemical is dissolved in discarded wooden or metal barrels and applied by dipping with a pail. This method is only applicable at batch-mix plants, and such barrels will give but a few weeks service.

Ferric chloride is rough on the hands and rubber gloves should be worn if direct contact with the solution is necessary. Occasionally, men mixing the anhydrous form complain of irritation to the eyes and throat. A chlorine canister mask may be worn in such cases.

In the preparation of ferric chloride solutions there appears to be some advantage in weak solutions, say 10 per cent, rather than 20 or 30 per cent. A high percentage solution can be prepared and diluted

with water in the feed line just prior to sludge conditioning. All Connecticut plants have sufficient storage for ferric chloride solution to last a 24-hour shift.

The lines carrying ferric chloride solution should be of heavy rubber hose, hard-rubber pipe, or rubber-lined pipe. The bolted flanges on hard-rubber pipe at one plant have leaked, and it is too early to predict the outcome of this difficulty.

Lime is being used in the hydrated form or as prestolite (also called, "prest-o-lime"). A high CaO content lime should be purchased, as free of magnesium as possible. (Prestolite runs about 37 per cent available CaO.) In New England two types of hydrated lime are readily available. While either is suitable for sludge pH control in digestion tanks, only No. 2 should be used for sludge filtration work. An average analysis of these limes follows:

	No. 1 High-Magnesium or Dolomitic Hydrate	No. 2 High Calcium Hydrate
Ignition loss	20.00%	24.90%
Silica	1.36%	0.30%
Iron-alumina	0.64%	0.20%
Calcium oxide	46.00%	73.70%
Magnesium oxide	32.20%	0.70%

Prestolite appears to be none too favorable a conditioning chemical. The available CaO varies and this makes good sludge conditioning an uncertainty.

Dry lime can be used for sludge conditioning but far better mixing is obtained by first preparing a milk of lime. Portable electric mixers are useful for this purpose. The reaction between sludge and lime appears to be slower than with ferric chloride, and a lime solution hastens the reactions which must occur for proper conditioning. Dry lime, applied directly to the sludge, also is objectionable by causing a fine dust which covers equipment and fills the throat. Suppression of this dust is difficult.

A number of laboratory tests have been made at Connecticut plants, using a Buchner funnel set-up to determine the suitability of chemicals other than ferric chloride for sludge conditioning. Alum and ferric sulfate in particular have been tried and the latter used on a plant scale at two installations. At one of these, handling raw sludge, the results were definitely disappointing. The filter cake was thin, sludge conditioning was difficult, and the filter cloth became rapidly clogged. The present market price of ferric chloride makes this chemical the most likely coagulant for use. Practical experience in this matter again appears to check laboratory work as reported by Mohlman and Edwards.[13]

In order to secure varying detention periods for the conditioning chemicals and sludge in continuous-mix tanks, it should be possible to introduce the chemicals at different points in the tanks. How long the chemicals and sludge should be mixed is a matter for each plant

superintendent to decide. The tendency is to mix *too long*. Generally 5 to 8 minutes should be ample for ferric chloride; in some set-ups only 2 or 3 minutes is required. The lime mix should not ordinarily require more than 5 to 10 minutes.

The order of addition, where lime and ferric chloride are both used, must also be considered in practical operation. It has been found at one raw primary sludge plant that the lime must be added last or the sludge is virtually unfiltrable; at another plant filtering raw chemically-precipitated sludge, little difference is noted and in fact, the chemicals are added practically together. A plant filtering digested sludge discovered that the lime is best added first, otherwise the rather vigorous mechanical agitation installed at this plant breaks up the floc produced by the ferric chloride and a poor filtering sludge results. However, laboratory work at this plant under *ideal* stirring conditions shows some advantage in adding the lime last.

Another point worthy of emphasis is the importance of using the optimum amounts of conditioning chemicals. That there is with most sludges a definite quantity of ferric chloride or lime, or both, either side of which poor filtering results are likely, seems established by field experience. An excess of chemicals may even produce a worse conditioned sludge, and cause more damage to filter cloth, than underdoses. The chemical costs of sludge conditioning exceed the costs for power and it is these former costs that should be watched. They can best be watched by frequent and carefully run Buchner funnel tests which will be described under "laboratory tests."

In order that the chemical requirements for conditioning various sludges throughout the country may be compared at different plants, the amounts of chemicals used should be reported by per cent on a dry basis. The ferric chloride is recorded as the pounds of pure anhydrous ferric chloride used per 100 pounds of dry solids filtered, *i.e.* per cent of dry solids. The dry solids should include the *sewage* dry solids and the *dry ferric chloride* added.

The lime used in sludge filtration is recorded as the pounds of available CaO used per 100 pounds of dry solids, *i.e.* per cent CaO of dry solids. The weight of dry solids includes in this case the weight of the dry *sewage* solids and the weight of *commercial lime* (the lime is assumed to be free of moisture).

Laboratory Control of Vacuum Filtration

Like any process in sewage treatment, if certain laboratory tests are intelligently made and applied, the vacuum filtration of sludge can be improved in efficiency and the cost of operation reduced. The tests suggested are: (1) Specific gravity, when desired, of unconditioned sludge and ferric chloride solutions. (2) Dry solids in the unconditioned wet sludge and filter cake. (3) Observation of color and determination of suspended solids, total solids, pH, and occasionally B.O.D. of the filtrate. (4) The Buchner funnel test.

With the exception of the Buchner funnel test the procedures for determining the above tests can be found in "Standard Methods for the Examination of Water and Sewage" (American Public Health Association, New York City).

If the chemical doses for filtration are to be reported on a dry basis, the dry solids determination for the unconditioned sludge is necessary. The digested sludge cake at one Connecticut plant averages 60 per cent moisture; the raw sludge cakes at two other plants average 70 and 74 per cent, respectively. Limited runs with an elutriated digested sludge cake show moistures of about 63 per cent.

A pronounced amber color in filtrates indicates excess iron. High turbidity indicates excess lime or holes in the filter cloth. In the latter case sludge solids are also frequently present. The suspended and total solids in a filtrate will run reasonably constant at a given plant—sudden jumps in these figures generally mean the cloth needs attention or replacement. Filtrates from digested sludge average better analytically than raw sludge filtrates. Total solids in raw sludge filtrates in Connecticut run about 0.7 to 1 per cent, suspended solids 50 to 200 p.p.m. Digested sludge filtrates run about 0.2 to 0.5 per cent total solids and generally under 100 p.p.m. suspended solids. Sometimes the suspended solids are only 10 to 20 p.p.m.

The pH of filtrates frequently can serve as a quick control of proper conditioning. Connecticut plants using lime and ferric chloride show values generally of about 10.5 with well-conditioned sludge. The pH of elutriated sludge at Hartford using ferric chloride alone has to date shown a pH of 6.3 to 6.5. Efforts should be made to correlate Buchner funnel tests and the pH of the filter feed.

The B.O.D. test on filtrates is primarily of theoretical interest and the values will be found to be considerably lower than for digestion tank overflow liquor. Usually the B.O.D. of filtrates will run under 2000 p.p.m. Figures less than 500 p.p.m. and over 3500 p.p.m. have been obtained. A filtrate is a far easier liquor to handle at a sewage plant than digestion tank liquor and it should, theoretically at least, aid slightly in the sedimentation process. In cases where sludge is too heavy for filtration, filtrate might be considered as the diluent, thereby utilizing the iron already present in this liquor. Mohlman and Edwards have pointed out in such cases, however, that chlorine would be necessary to convert the ferrous chloride to ferric.

The Buchner funnel test is a useful and practical determination which should be employed at vacuum filter plants for both routine and special testing. While the test is generally known to sewage chemists and many engineers, its adaptability and practicality for plant use is not always appreciated by plant operators and engineers. The reader will find a suitable description of this test in an article in *This Journal* by A. L. Genter entitled "Adsorption and Flocculation as Applied to Sewage Sludges," pages 698–700, July, 1934.

Interpretation of Funnel Tests.—The amount of chemicals used

can be plotted against the filtration rates in grams of filtrate and cake per minute as described and discussed by Genter. However the sewage plant operator may simply tabulate his chemical doses and time for vacuum break and arrive at the optimum dosages for his particular sludge. Table I illustrates the procedure.

TABLE I

Sample No.	$FeCl_3$ cc. Used	Lime, Grams Used	Time for Vacuum to Break
1	0.5	1	+5 min.
2	3.0	1	2 min.–40 sec.
3	5.0	1	1 min.–20 sec.
4	2.0	2	1 min.–30 sec.
5	1.0	3	1 min.–50 sec.

By making sufficient tests with varying amounts of coagulants the most economical doses can be determined to obtain an optimum filtering time.

Applications of the Funnel Test.—The following applications of the Buchner funnel test are listed as worthy of operators' consideration:

1. For checking the conditioned sludge before delivery to the filters. Blinded cloths can frequently be avoided by this check-up, and the test is particularly useful at batch-mix plants.
2. The length of time a conditioned sludge can be held before filtering can be determined.
3. Trouble with the filters can be located with greater simplicity. For example, blinded cloth may be the cause of filtration difficulty and not the sludge conditioning. A funnel test will quickly reveal this.
4. Variable mixing periods and the best manner of mixing for a particular sludge can be determined.
5. The order of addition of the chemicals and the desirable time lapse between additions can be checked.
6. Various commercially available coagulants can be tried on the sludge at less cost and inconvenience than on a plant scale. Promising chemicals can then be given a plant trial.
7. Chemical savings can frequently be shown by regular laboratory check-ups on the sludge conditioning.
8. The test is useful in determining the filtrability of sludge at plants where sludge beds or centrifuges are now in use for sludge dewatering. The results may show low or high costs depending on the character of the sludge. These tests should preferably be made on both summer and winter sludge.
9. Many miscellaneous experiments can be conducted which might indicate the advantage of filter alterations, such as, sludge concentration facilities, elutriation, changes in sludge feed, etc.

Operators sometimes report difficulty in preparing conditioned sludge in laboratory beakers that will check with sludge conditioned with the plant equipment. If a series of beakers are set up in such cases and various stirring times given sludge containing the same amounts of coagulants as the plant-prepared sludge, check tests can be made. The sludges are run through funnels including the plant sludge, and that sludge which checks the plant sludge in filtering time is the one that has been mixed more nearly in the same manner. Future laboratory mixings can then be performed in the same manner. This and other discrepancies in the test can be eliminated if a particular plant set-up is studied. When a careful technic has been developed and a record of the results are kept, this test can be made to serve many useful purposes in the operation of vacuum filters.

How to Make a Yield Check on Vacuum Filters

The yield of vacuum filters is measured by the pounds of dry solids removed per square foot of filtering area per hour of filtering. This is the usual manner of reporting. There are three common methods of computing this:

(*a*) If the volume of filtered sludge is measured in gallons, and a composite sample of the *conditioned* sludge is collected for dry solids determination, the pounds of dry solids per sq. ft. per hour removed by the filter can be computed by dividing the total pounds of dry solids in the sludge by the product of sq. ft. of filter area and hours of running. If only the removal of *dry sewage solids* is desired, the solids determination is made on the *unconditioned* sludge. The usual way of reporting is, however, to include the weight of chemicals.

(*b*) Yields can readily be computed from the weight of the filter cake. Totalizers, which weigh the cake while it moves on conveyors, are available, or the cake can be weighed in trucks using platform scales. A composite sample of the filter cake is collected during the run and the per cent of moisture computed.

(*c*) Filter cake samples of known weight and area are collected from the filter apron during a definite time interval, while the filter drum is held to a constant speed. The pounds of wet cake being produced per revolution of the filter are thus computed and after the dry solids in the wet cake are determined, the total weight of dry solids for the run is known. The yield in lbs. per square foot per hour can then be reported.

Disposal of Filter Cake

Methods of Disposal.—A discussion of vacuum filtration of sludge may logically include remarks on the disposal of the final product—the filter cake. The following means for disposal are used at Connecticut plants either in operation or under construction:

Method of Disposal	*Number of Plants*
Incineration	4
As fill	2
As a soil conditioner	1

At one plant an elutriated digested sludge cake is being used primarily as fill in a low area remote from dwellings. The appearance of the exposed sludge in this case is not important. There are no carrying odors from this material and flies are not particularly attracted. This material could be dumped near dwellings without a nuisance.

A raw sludge cake rather heavily conditioned with ferric chloride and lime is also being used for fill at an ash and rubbish dump. The ground at the dump is marshy. This material does not have a carrying odor when exposed in small amounts, but an objectionable odor does develop if large quantities are left exposed. The high pH (10.5 to 12) in the cake retards the decomposition of the material and temporarily prevents offensive odors. It has proven advisable to cover this sludge with at least a shallow earth layer and this is being done. Odors have been under control during approximately a year's operation.

While flies do not breed in the dry cake from this plant, they are attracted and its exposure is, therefore, somewhat of a health menace. Observations have also shown that the interior of the fill is heating considerably and there is some danger of spontaneous combustion starting an odorous fire. Sludge burning in the open emits an offensive odor and is bound to result in complaints. The construction of fire walls consisting of earth banks might prove a desirable precaution to prevent the burning of sludge in built-up sections.

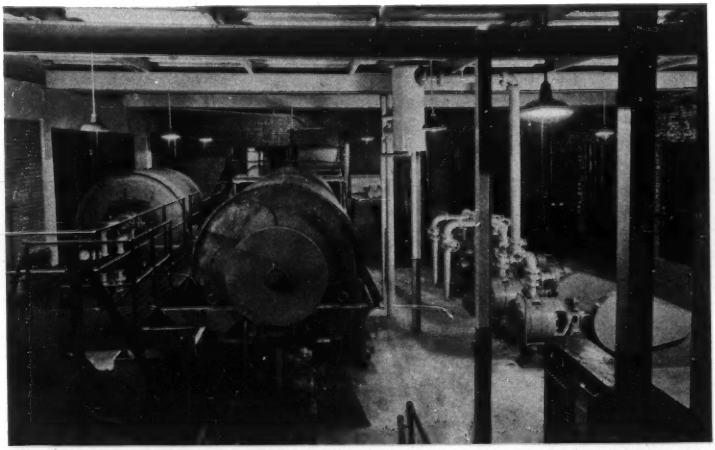

FIG. 6.—New Britain, Conn., vacuum filter room. Note cake elevator in lower left-hand corner, and chemical feed tanks in center rear.

A digested sludge cake conditioned with ferric chloride and lime is being given away at one plant as a soil conditioner. This scheme has proven so successful that a sludge incinerator built in conjunction with the vacuum filter installation has not been operated to any extent.

Connecticut's remaining vacuum filter plants do or plan to incinerate the cake (Fig. 6). Incineration will be but briefly mentioned. Our experience seems to indicate that raw sludge cake is more likely to upset incinerator operation than digested sludge cake. This appears to be caused by a fluctuating volatile content in raw sludge cake, more variable conditioning, and a tendency under some conditions for the cakes to run wetter and less uniform in moisture. Temperatures must be carefully watched during incineration and pre-heaters, when provided, protected against overheating.

A gas analyzer is a valuable adjunct to incinerator operation. Ideal burning is indicated by the following approximate flue gas analysis:

Carbon monoxide (CO)	Trace
Carbon dioxide (CO_2)	9–10%
Oxygen (O_2)	7– 8%

The furnace feed must be designed to prevent clogging by a wet cake and to deliver the cake over a flexible load range to harmonize with the filter yields. Feeders have given these troubles.

All of the furnaces in this state are of the multiple hearth type with moving rabble arms. These furnaces according to my observations, have operated without odor, excessive smoke or other nuisance. Analyses of the ash have shown not more than 3 per cent, and frequently less than 1 per cent, of organic matter.

TABLE II.—*Bacteria in Sludge and Sludge Cakes*

Sample of	Standard Plate Count Colonies per Gram	Coliform Organisms Confirmed in Ml. shown	pH
Raw unconditioned sludge (IA)	114,000,000	0.0000001	5.8
Raw conditioned filter cake (IB)	45,000	0.1	11.8
Raw unconditioned sludge (IIA)	10,600,000	0.000001	6.5
Raw conditioned filter cake (IIB)	49,000	0.001	10.5
Raw unconditioned chemically-precipitated sludge (IIIA)	44,000,000	0.0000001	6.4
Raw conditioned filter cake (IIIB)	850,000	Absent in 0.1*	10.6
Digested unconditioned sludge (IVA)	1,750,000	0.0001	7.0
Digested conditioned filter cake (IVB)	56,000	Absent in 0.1*	10.3
Digested unconditioned sludge (VA)	32,000,000	0.000001	7.1
Digested elutriated conditioned filter cake (VB)	39,000,000	0.0001	6.3
Air-dried digested sludge cake (VI)	28,000,000	0.001	7.1
Air-dried digested sludge cake (VII)	23,000,000	0.01	6.7
Air-dried digested sludge cake (VIII)	1,200,000	Absent in 0.1*	6.8
Digested sludge (IXA)	4,500,000	0.000001	6.9
Air-dried digested sludge cake (IXB)	216,000,000	0.00001	6.8

* 1 ml. and 10 ml. portions were not examined.

Bacteria in Filter Cake. Table II shows some results of bacterial examinations of sludges before conditioning and of air-dried sludge

cakes and filter cakes, the latter collected with sterile forceps directly from the discharge apron of the filters. These tests were made under the direction of C. C. Carson, Chief Chemist of the Connecticut State Department of Health laboratories.

Table II shows high reductions in both plate counts and coliform organisms in filter cakes with high pH values, as might be expected. Hygienically, sludge cake with high pH's has apparently some factor of safety. This factor is by no means absolute, however, and the usual precautions should be followed in handling it. From a comparison of the limited samples reported above, filter cake conditioned with lime appears to contain fewer bacteria than air-dried sludge. The air-dried samples reported were collected from sludge beds after 2 to 4 weeks of storage.

Grease or Fats in Filter Cake.—A study of the grease in a number of filter cakes reveals an average content of about 6.5 per cent (dry basis) with a variation from 4 to 13 per cent for both raw and digested sludges. The Connecticut Agricultural Experiment Station believes, as do others, that under average conditions the soil bacteria will assimilate this amount of grease without fear of soil clogging.

Iron in Filter Cake.—The question of iron in filter cakes is of interest. The total iron as Fe (dry basis) has varied in samples at Connecticut plants from 1.4 to 3.7 per cent with the average about 2 per cent.

Lime Content of Sludge Cake.—The Ca $(OH)_2$ content (dry basis) of sludge cakes has run as high as 15 per cent in some samples collected.

Records for Vacuum Filter Operation

The daily plant log should include the following data whenever possible:

1. Gallons of sludge filtered.
2. Per cent dry solids in sludge.
3. Per cent volatile solids in sludge.
4. Amount of ferric chloride, lime or other chemicals used, reported on a dry basis.
5. pH of the filter feed. (The pH of the filtrate is determined as this is also the pH of the conditioned wet sludge and the sludge cake.)
6. Per cent moisture in filter cake.
7. Suspended solids and total solids in filtrate.
8. Filter run in hours.
9. Lbs. of wet filter cake.
10. Lbs. of dry solids filtered.
11. Filter yield in lbs. per sq. ft. per hr.
12. If elutriation is employed the solids in the unelutriated and elutriated sludge, and the suspended solids in the elutriate should be reported.

Filtration Data on Various Sludges

A summary of operating results at four vacuum filter plants in Connecticut is presented in Table III below:

Table III

	Plant A	Plant B	Plant C	Plant D
Population served	70,000	23,000	21,000	200,000
Av. dry weather flow, M.G.D.	8.0	1.8	1.4	40.0
Type of sludge handled	Raw, chemically precipitated	Raw	Digested	Elutriated digested
Average solids in unconditioned sludge, %	8.0	6.0 to 7.0	15.0 to 17.0	14.0
Men employed on filter operation	1	2	2	2
No. filters	3	2	1	2
Total filter area	600	113	94½	700
No. of filters used at one time	1	2	1	1
Average operating time of filters per week, hrs.	132	52½	7	32
Filter cloth, hours of use	300–325	225–250	250	—
Average pH of filter feed	9 to 10.5	10.5 to 12.0	10.5	6.3 to 6.5
Chemicals used, dry basis, %				
$FeCl_3$, Av.	1½	5½	2 to 3	1¾
CaO, Av.	12 to 13	12 to 14	6	None
Per cent moisture in filter cake, av.	74.0	69.0	60.0*	63.0
Average thickness of cake	¼ in.	⅜ in.	⅜ to ½ in.	¼ to ⅜ in.
Lbs. dry solids filtered, weekly av.	104,650	7,600	4,000	70,000
Av. filter rate, lbs. sq. ft. per hr.	3.4	1.1	5.6	6.3

* Cakes as low as 52 per cent moisture have been obtained.

Conclusion

A paper has been presented on experiences with the vacuum filtration of sludge. An effort has been made to present information of interest to the men actually operating filters.

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RESULTS OF FIRST NINE MONTHS' OPERATION AT NEENAH–MENASHA *

By J. M. Holderby

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The Neenah-Menasha Sewage Treatment Works comprises a mechanical bar screen with an automatic screenings shredder, a pump station, chemical feed equipment, clarifiers, sludge storage tanks, vacuum filters and a sludge incinerator. The plant is designed to treat sanitary sewage from some 25,000 people and manufacturing wastes from the local paper industry. Further details of the physical set up of the plant can be obtained by reference to an article by S. A. Greeley in the November, 1937, issue of *This Journal.*

Sewage in small volume was first turned into the plant in September, 1937. By January 1, 1938, a substantial portion of the expected wastes had been intercepted and operations had approached a routine.

Operating results, for the first nine months of 1938, can perhaps best be presented through the medium of the tabulations accompanying this report and discussed briefly below.

Pump Station.—The two collection systems tributary to the treatment plant were originally constructed on the combined plan and have as yet been only partially converted. Accordingly, extremely high flows are experienced during stormy weather. Large variations in flow occur even during dry weather periods as a result of week-end shut downs at the tributary paper mills. When the pumpage rate exceeds 10 m.g.d. a by-pass weir starts functioning. Data in Table I

Table I.—*Sewage Quantities—Summary 1938*

Month	M. Gal. to Clarifiers			Pumping Power K.W.H.	K.W.H. per M. Gal. Metered	Estimated Pumpage M. G.[1]
	Total	Max. Day	Min. Day			
January	96.9	5.2	1.0	9,500	98.0	96.9
February	196.7	11.8	2.4	19,000	97.6	196.7
March	269.4	11.9	4.9	26,400	98.0	269.4
April	218.0	11.3	4.1	22,800	104.5	232.0
May	213.8	9.6	3.3	22,970	107.3	234.0
June	171.5	11.7	2.1	19,780	115.2	202.0
July	166.9	9.5	2.5	18,920	113.3	193.0
August	208.7	9.5	2.6	21,330	102.0	217.5
September	187.3	10.6	2.0	33,370	178.0	340.0

[1] Calc. —98 K.W.H./mil. gal.

indicate that the minimum twenty-four hour flow experienced has been 1.0 million gallons, with a maximum of 11.9 million gallons. The maxi-

* Presented at the Eleventh Annual Convention of the Central States Sewage Works Association, Neenah-Menasha, Wis., Oct. 13, 1938.

mum pumpage rate has been approximately 30 million gallons per day. Comparing the flow through the clarifiers (metered) with the calculated pumpage reveals that, due to excessive rates of flow, substantial quantities of sewage have been by-passed during all months except the first three.

Sedimentation Units.—The sewage received at the plant has varied from straight domestic to a mixture which at times has consisted of as much as six volumes of paper mill waste to one volume of domestic sewage. The influent is normally rather high in total suspended and settleable solids and relatively low in volatile suspended solids and B.O.D.

Average suspended solids reductions have usually been well above 60 per cent (Table II) and settleable reductions above 90 per cent, except for the months of March, April and September, during each of which, excessive amounts of infiltration diluted the sewage and decreased the theoretical sedimentation periods. Average B.O.D. reductions range from 20.3 to 35.7 per cent.

TABLE II.—*Sewage Characteristics and Sedimentation Efficiencies—Summary 1938*

Month	Suspended Solids				Settleable Solids		5 Day B.O.D.		pH Raw	Ave. Detention Hrs. (theoretical)
	Total		Volatile							
	Raw p.p.m.	% Red.	Raw p.p.m.	% Red.	Raw c.c./2 hr.	% Red.	Raw p.p.m.	% Red.		
Jan.	561	65.0	321	71.6	21.9	97.9	—	—	8.0	5.1
Feb.	432	61.6	244	69.4	23.2	87.5	143	23.1	7.7	2.3
Mar.	366	53.5	200	60.9	18.5	86.7	126	20.3	7.8	1.8
Apr.	340	50.3	185	56.0	14.6	88.7	130	24.7	7.5	2.2
May	413	65.9	243	76.1	21.9	94.8	166	28.6	7.3	2.3
June	443	63.2	253	69.1	18.4	95.9	193	29.1	7.3	2.8
July	391	63.0	174	72.0	16.4	92.7	159	35.7	7.4	3.0
Aug.	426	64.6	206	76.0	20.8	95.4	162	32.8	7.4	2.4
Sept.	263	49.5	117	62.2	11.3	88.2	95	28.0	7.6	2.0*
Average	404	59.6	216	68.2	18.6	92.0	147	27.8	7.6	2.7

* Est.—North Clarifier out of service 13 days.

Considering the detention periods afforded (ave. 2.7 hrs.), the reductions accomplished are perhaps somewhat less than might be expected from experience elsewhere. The sewage being treated is, however, so far from the orthodox variety that it may not be altogether fair to draw comparisons. So far, opportunity has not been found to study in detail the settling characteristics of the paper mill solids nor the ratio of the settleable portion of the B.O.D. to the non-settleable portion in the combined influent. Investigation of these unknowns might well explain why removals in general have not been higher.

It is considered that for the major part of the time the most important function of the Neenah-Menasha plant is to keep out of the Fox River those solids which, if discharged, would result in extensive sludge bank formation. It is believed that this function is being fulfilled.

Dewatering.—Raw sludge with an average solids content of 8.1 per cent has been successfully filtered after conditioning with calcium hydrate and ferric chloride. In Table III it is showed that conditioning

TABLE III.—*Sludge Dewatering—Summary 1938*

Month	Sludge		Conditioning		Power K.W.H. per Ton D.S.	Cake		Filtrate Ph. Alk. P.p.m.[1]
	Dry Solids Per cent	Dry Solids Tons	$FeCl_3$ Per cent	$Ca(OH)_2$ Per cent		Dry Solids Per cent	Yield lb./sq. ft. hr.	
January	8.7	201.8	1.4	7.8	22.1	36.4	4.45	—
February	8.1	232.4	1.4	6.4	26.9	33.0	3.20	—
March	7.2	252.9	1.7	5.9	28.6	31.2	3.46	549
April	7.5	192.6	1.9	5.7	26.8	32.7	4.05	271
May	8.0	262.1	1.7	5.4	27.0	33.9	3.58	109
June	8.5	318.2	1.3	5.7	22.7	33.4	3.78	303
July	8.4	268.4	1.0	6.1	19.7	36.4	4.81	657
August	8.7	284.0	0.8	5.7	18.9	33.5	6.95	490
September	8.2	153.1	0.9	6.0	20.1	33.8	5.73	601
Average	8.1	—	1.3	6.1	23.6	34.0	4.45	426

[1] Equals sum (OH) + $\frac{1}{2}$ (CO_3).

chemicals have averaged 1.3 per cent for ferric chloride and 6.1 per cent for lime. The filter cake produced has averaged 34.0 per cent solids and the average yield has been 4.45 lb. of dry solids per hour per sq. ft. of filter area. Power requirements for conditioning and filtering have averaged 23.6 K.W.H. per ton of dry solids.

It is pointed out that the results here shown cover a period during which inexperienced personnel were operating new equipment and that accordingly trends should be considered in preference to actual averages. Difficulty has been experienced in attempting to supply the conditioning tank and filters with sludge of uniform consistency. It was found necessary to add more or less water to the sludge to get it to flow through the original piping in sufficient quantity to keep up with the filters. This condition, which is currently being remedied by revision of the sludge piping, has made close control of conditioning next to impossible and has forced the frequent use of two filters when one should have been ample but did not actually produce quite enough cake to keep the incinerator loaded to the desired degree.

No altogether satisfactory control test has as yet been worked out for the dewatering operation. Observation of several characteristics has, however, resulted, for the time being at least, in the phenolph-

thalein alkalinity of the filtrate being used in this connection. The filtrate always contains caustic alkalinity and the phenolphthalein value was selected as a control rather than the total alkalinity because of the precision with which the shift operators can arrive at the end point of the titration. At present we are attempting, with by no means gratifying success, to hold the phenolphthalein alkalinity below 300 p.p.m. After all is said and done, the filters must produce so much cake and regardless of the control tests the operator must get out the required production.

Present experience indicates an average running life of about 250 hours for the filter cloths we are now using, with ultimate failure being ordinarily due to tearing. The tears usually occur over the separation strips in the filter drum and there is evidence that they are the result of the cloth fibers being weakened by rotting rather than by mechanical strain. During the earlier months of operation filter cloths frequently failed after as little as 100 hours by filling up on the back side with thick deposits of carbonate. This condition prevailed in spite of all attempts to remedy it until, in desperation, a very light and cheap outing flannel was adopted so that the cost of replacement would be minimized. To everyone's surprise the flannel did not fill up appreciably and continued to filter until it failed by tearing. At present a medium weight of outing flannel is standard for our filters.

Incineration.—Table IV summarizes operating data for the sludge dryer and incinerator. Briefly the data show that the average performance has been to burn sludge solids containing 47.3 per cent combustibles at a rate of 0.745 tons per hour, with a fuel oil consumption of 20.8 gallons per ton.

TABLE IV.—*Neenah-Menasha Sewage Treatment Works*

Month	Dry Sludge		Power K.W.H. per Ton D.S.	Hours Operated	Evaporation Pounds per Hour	Loading Tons Dry Solids per Hour	Fuel Oil Gallons per Ton D.S.
	Total Tons	Combustible %[1]					
January	201.8	44.0	73.5	269.5	2511	0.749	36.4
February	232.4	47.0	67.4	332.5	2743	0.699	25.3
March	252.9	48.5	69.5	370.0	2951	0.684	25.4
April	192.6	51.8	65.9	269.5	2890	0.715	22.7
May	262.1	48.6	72.6	377.5	2709	0.695	23.5
June	318.2	46.9	63.6	417.8	2739	0.762	16.3
July	268.4	42.2	59.7	332.0	2811	0.808	15.4
August	284.0	48.6	62.6	356.8	3141	0.795	10.8
September	153.1	47.8	63.9	193.0	3098	0.794	11.4
Average	—	47.3	66.5	—	2844	0.745	20.8

[1] Ash corrected for CO_2 loss.

As pointed out in connection with the dewatering operation, however, it is believed that the unavoidable difficulties attending the break-

ing in of a crew and new equipment justify giving more weight to the trends indicated in Table IV than to the average shown. The economical operation of a flash dryer and of an incinerator of the Combustion Engineering type depends among other factors upon the uniformity of feed, the degree of loading and the continuity of operation. Cumulative experience with the equipment has permitted each month a closer approach to the ideal for all of these factors and results for succeeding months have accordingly shown progressive improvement.

Routine calorific determinations have not been made on the sludge going to the incinerator. Such determinations as have been made indicate that the dry sludge produces from 3,500 to 4,500 B.T.U. per pound. The low fuel value of the sludge is due to the presence of much clay, whiting and other paper filler materials discharged by certain of the paper mills.

Chemical Treatment of Sewage.—At the present time no plant scale data are available concerning the chemical treatment of sewage. Chemical treatment facilities were installed in the plant with the expectation that they would be utilized only during the critical summer months when the combination of low stream flow, low dissolved oxygen in the stream and high water temperatures would indicate a step up in the degree of treatment afforded the sewage. During the past summer the discharge and the dissolved oxygen concentration of the Fox River have continuously been so high that at no time has the excess available oxygen in the stream entering the Neenah-Menasha section been less than seven times the 5-day demand of the plant effluent. Under such conditions the expense of chemical treatment during the past summer was deemed unjustifiable.

LEGAL ASPECTS OF SEWER RENTAL LAWS AND CONNECTIONS FROM OUTSIDE TO CITY SEWER SYSTEMS *

By Homer Buckley

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This topic is divisible into two subjects; first, the "legal aspect of sewer rental laws," and secondly, the "legal aspect of connections from outside to city sewer systems." I will treat them separately.

First, the "legal aspects of sewer rental laws." Under the heading of laws I intend to take up questions of legislative acts and decisions of the courts. The courts sometimes have not been able to agree just what constitutes a law, so for the purpose of our discussion I will define a law to be an enactment of the state legislature or a decision of the court of last resort.

The only act that I know of in the state that gives a municipality the power to levy a sewer rental fee for the use of the city sewer system is an act passed in 1935 and generally known as the "Sewer Revenue Bond Act." This act sets up a procedure for the issuance of bonds for the construction of sewer systems and the borrowing of money from the R.F.C. The act is not available unless you use R.F.C. money. However, the act has some possibilities in that it can be amended and these limitations stricken out, in which case you would have a general act under which a city could construct a sewer system under what is equivalent to revenue bonds. The act provides that in order to retire those bonds the City Council shall fix a fee for the use of the sewer system, and that the fee so fixed must produce an amount of money sufficient to pay for the redemption of bonds, payment of interest, maintenance and repair. But as the law stands today, it is practically useless for any practical purpose because to use it the city must have R.F.C. money; but it does have possibilities by way of future amendment.

We have an act with which all of you are acquainted—the Municipal Corporation Act. The language relating to cities of the sixth class is as follows: "to construct, establish and maintain drains and sewers." Immediately the problem arises as to whether or not a fifth or sixth class city can, under this grant of power, levy and collect a sewer rental fee. This problem arose in the case of City of Madera v. Black, 181 Cal. 306. The City of Madera voted bonds for the purpose of purchasing a then existing private sewer system. In 1914, after the purchase of the system, the City Council passed an ordinance making it illegal for any person to live in any building unless that building was connected with the sewer disposal system, and provided for a "monthly sewage rate or charge for the use of and connection with the sewer,

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the rate for each dwelling house occupied by a single family being one dollar, payable monthly in advance on the first day of each month." The ordinance also provided that upon failure to pay the fee, a penalty should be imposed of $10.00 in addition to the accrued sewer rental, and that the rental should be a debt to the city and could be called by a civil action. A fellow by the name of Black, being an independent sort of a fellow, didn't like the idea, and he refused to pay the fee. At the end of thirteen months the city brought action against him for $13 plus the $10 penalty. At the time of trial Black proved certain things which are very interesting to us, I think. I will state the figures in round numbers. At the time of trial it was proved that the City of Madera had collected under this ordinance some $40,000 in sewer rental fees. Of that amount of money $21,000 had been transferred to the General Fund of the City, $8,000 had been transferred to the Water Fund and $1,000 transferred to the Sewer Bond Redemption and Interest Fund. Black argued that by virtue of the fact that the ordinance created a debt for the amount of the sewer rental and provided for its recovery in a civil action, that the City was engaged in carrying on a business and was therefore engaged in what is called a proprietary function. He argued that a city of the sixth class had no power to operate a sewer system as a proprietary function, and therefore the ordinance was invalid. The court, in discussing this aspect of the argument stated as follows:

> If the argument of respondent that it is a debt is tenable, it must be upon the theory that the city, in its proprietary capacity, is the owner of the sewer, and that it was operating the same in that capacity. This necessarily assumes that the city by its organic law was authorized to construct and operate sewers in its proprietary capacity for profit or otherwise, as a private person might do.

In discussing this problem, I want you to keep in mind that in this State we have two kinds of municipalities, those that are organized under the Municipal Corporation Act and those that are organized under a Freeholders' Charter. A city of the sixth class and a city of the fifth class have their corporate existence by virtue of their organization under the Municipal Corporation Act, a statute of the Legislature, and a chartered city owes its existence to a provision of the Constitution. These two classes of cities are very different insofar as the powers that are granted to each; a sixth class city only has those powers which are expressly and directly granted to it. As the court says here:

> Madera, being a city of the sixth class, its powers are defined solely by our statutes. Among those powers we find none authorizing it to acquire, construct or operate sewers in its proprietary capacity for the purpose of obtaining revenue or profit therefrom. It is given power "to construct, establish and maintain drains and sewers."
>
> . . . . . .
>
> It is the settled law of this state and the general rule everywhere that "language purporting to define the powers of a municipal corporation is to be strictly construed" and that any "fair reasonable doubt concerning the existence of the power is resolved by the court against the corporation and the power is denied."

Madera is a sixth class city; therefore its powers are defined solely by statute, the Municipal Corporation Act, and such powers are to be strictly construed.

The language I read to you a moment ago gives to the City of Madera the power to "construct, establish and maintain sewers and drains," and the court in the Black case said:

> But it is obvious that the power to construct and maintain sewers does include authority to raise revenue for general purposes by means of a toll or tax for the privilege or right to use the sewer for the purposes for which it was constructed.

The only conclusion that can be drawn from the case is that the City of Madera was operating its sewer system as a police power function, as distinguished from a proprietary function.

We encounter another fundamental principle that arose in this case. If a city is levying licenses for purposes of regulation, that is by an exercise of its police power, the amount of license that may be charged shall be only enough to pay for the cost of supervision and regulation. If a city levies a license in a proprietary capacity or for revenue purposes, the only limitation is that the license must not be so great as to constitute confiscation.

In the language I have just read, the court came to the conclusion that the City of Madera was not carrying on its sewer system in a proprietary capacity. Therefore the court says the amount of the license that the City of Madera could collect could not exceed an amount of money necessary to pay for the operation and maintenance of the sewer system, and that the use of such license fees for general fund purposes was beyond the power of the city. The court used the following language:

> But the rates here imposed upon the sewer users were obviously for purposes additional to that of paying the expenses of repair and maintenance. . . . This would be an unfair discrimination and unfair burden upon those who use the sewer and it is clearly beyond any power possessed by the city. It follows that the charges were excessive and unreasonable.

The court stated that if any of the license fees taken in for sewer rentals had been used for the purpose of extending the sewer system, such a use would be unlawful. I will continue with the language of the court:

> If any (sewer rental) was used for extensions to the sewer system, such use was unlawful, and it cannot be doubted that the city has no power to lay taxes or tolls upon those who use the sewer in order to obtain money to build sewers in other streets for the special benefit of other persons.

These sewer bonds were voted under the Bond Act of 1901, our general bond act in this state—that is, general obligation bonds. That act provides that a city council shall each year at the time of levying taxes include an amount of money sufficient to pay for outstanding bonds that are to be redeemed during the course of that year, and an amount of money sufficient to pay the interest on the outstanding bonds. The court says that under that act the method of raising money to redeem

bonds and of paying the interest was fixed, and therefore the city council had no power to raise money by way of a sewer license or a fee to meet this obligation. In this regard the court says:

> The payment of the principal and interest of the bonds issued as aforesaid is to be paid out of money raised by a general tax upon property as provided in the act authorizing their issuance. No money raised by sewer rates would be necessary to pay those bonds or could lawfully be used in that manner.

Therefore we have a decision in which the court has held that the city in levying a sewer license was not acting in a proprietary function but in a police power function, that the amount of the license levied was excessive, that the court would not attempt to determine what a reasonable amount was and therefore set aside the entire amount of the license. The court says:

> A court cannot apportion the charge or ascertain and allow such portion as it might find reasonable. . . . The entire charge must therefore be declared invalid.

That is the conclusion reached as to the law relating to cities of the sixth class.

A chartered city is in a different situation. Under the Constitution, Sections 6 and 8 of Article XI, a city which holds a freeholders' charter is granted supreme power in all "municipal affairs." What a "municipal affair" is has never been completely defined. The courts have on many occasions said, this is a "municipal affair" and this is not; the only definition we have is either by inclusion or exclusion in specific cases.

The courts have said that the power to construct sewers and drains is incidental to the power to construct streets, and the court has held that the construction of streets is a "municipal affair." A chartered city is not dependent upon specific grants of power as is a sixth class city, but is supreme in all "municipal affairs," unless the charter contains some specific limitation. I think the decisions of the courts of this state are sufficiently broad to say that the Constitution provides that the operation and maintenance of any sewer system by a chartered city is a "municipal affair." That being so, I think a chartered city can levy a license either to pay the cost of operation, maintenance or replacement, or for the purpose of producing revenue for general purposes, unless there is something in the charter that specifically prohibits it. In other words, if the City of Madera had been a charter city, I believe the court would have come to a contrary conclusion and sustained the license.

At this point I think we can come to certain conclusions, most of them being negative. The first is that cities of the fifth and sixth class cannot operate a sewer system as a proprietary function; second, that such cities can operate sewer systems only as a police power function; third, that the money produced by a sewer rental can be used only for the purposes of maintenance and repair of the specific sewer system; fourth, that none of the sewer rental money can be used for the extension of the sewer system; fifth, none of such revenue can be put into

the general fund; sixth, it cannot be used for the water fund; seventh, it cannot be used to retire the bonds of your sewer system nor to pay the interest on those bonds; and eighth, that the amount of rental produced must not exceed the cost of operation and maintenance.

This brings us to the next aspect of our subject, namely, "city connections from outside to city sewer systems." In this aspect of our discussion the distinction between chartered cities and cities organized under the Municipal Corporation Act is of no importance, because it has been held that when a sewer problem goes beyond the boundaries of the city, it ceases to be a "municipal affair," and becomes a state affair. In such cases both classes of cities cannot function unless there is some specific grant of power. It has been argued by some lawyers that the constitutional grant of police power to make and enforce ordinances to protect the public health is sufficient authority to construct a sewer system in a congested unincorporated area adjacent to a populated community in order to protect the health of that community.

The City of Richmond, Virginia, under a similar grant of power, argued:

> We have here immediately adjacent, a very large residential area without any sewer at all, the resultant condition is so hazardous, the public health and public safety is so affected, that we believe the city should go outside of its limits and construct sewers.

As a result they passed an ordinance providing for the extension of city sewers in unincorporated territory. The matter went up to the Supreme Court of that state, and the court held that under the power to protect the health and safety of the people of the city, it could spend money beyond its corporate limits in order to protect its citizens. In Indiana a city did the identical thing, but the Supreme Court of that state came to a contrary conclusion. What the law is in this state I am in doubt. I am, however, inclined to the thought that the courts would not approve the construction of sewers by a city outside of its corporate limits upon the theory that it was protecting the health and safety of its own citizens.

In the case of *Mulville v. City of San Diego* (183 Cal. 734), we have an interesting case which throws some light upon the subject matter. In that case the City of San Diego organized an assessment district to construct a pleasure pier which projected from the land out into the ocean. There being no land which could be subject to assessment in the ocean, the assessment area ended at the water's edge. Thus the improvement was to extend beyond the boundaries of the assessment area. The action was attacked upon the ground that the City Council could not construct an improvement outside of the assessment area. The Supreme Court came to the conclusion that the objection was well founded and held that the city couldn't construct the improvement beyond the area which was assessed to pay for the improvement. This is very analogous to the power of a city to construct a sewer beyond the boundaries of the city which is taxed to pay for the improvement. This quotation is rather long, but I will read it to you:

In general a municipality is competent to act beyond its boundaries only in those cases in which it is so empowered by legislative authority, and it is necessary in passing upon the validity of acts of a municipality performed beyond its boundaries to look to the general laws and municipal charter for the requisite authority.

The general rule is that without legislative grant the authority of the municipal corporation is confined to its own area, hence its acts and ordinances have no force beyond its corporate limits. Thus, in the absence of such grant the municipality cannot open a street, repair a highway, grade an avenue, or aid in the construction of a plank road or bridge beyond its boundaries.

In subsequent decisions dealing with sewers the courts have limited the power of the city to go beyond its boundaries to outfalls, and in none of those cases has any city gone to the extent of authorizing or empowering the extension of the sewer system merely for the convenience of adjacent territory. Even the right to extend the outfall beyond the city has been fought over very strenuously. The language just quoted is a definite statement that is applicable to all cities of the state so far as their right and power to perform functions outside of their corporate limits is concerned. This conclusion has been substantiated in the recent case of *City of Oakland v. Brock* (8 Cal. (2) 639). The issue in that case was the power of the city to inspect slaughter houses outside of its corporate limits in the interest of the public health and safety of its citizens who purchased most of the meat slaughtered there. The court, in discussing this question, stated:

A municipal corporation has generally no extra-territorial powers of regulation. It may not exercise its governmental functions beyond its corporate boundaries. . . .

The authorities do not recognize extra-territorial regulation and inspection in itself as either necessary or indispensable to a governmental function in such cases. The decisions point to the obvious method of enforcing compliance with appropriate standards, viz., inspection at the city limits or, where that is inadequate, the requirement for a permit or license, and compliance with prescribed regulations as a condition precedent to the issue thereof.

When you get to the problem of the chartered cities, you get into the realm of "municipal affairs." An interesting case went to the Supreme Court of this state a few years ago, arising out of some problems in the construction of storm drains and sewers between an area in the City of Los Angeles and abutting areas in the City of Long Beach. In that case, *Torson v. Fleming* (91 Cal. App. 168), they used an act which has subsequently been repealed, known as the City Boundary Line Act, which set up a procedure whereby an improvement may be constructed to serve areas inside an incorporated city and an unincorporated area or area within two adjacent incorporated cities. In this case the question arose as to whether or not the construction of a sewer was a "municipal affair," and the Supreme Court stated the following:

Where the evil to be remedied reaches beyond the boundaries and jurisdiction of any one municipality—whether such extra municipal ill be due to an unimproved roadway extending into one or more municipalities, or to unsanitary conditions due to the lack of a suitable regional sanitary sewer system, or to a widespread overflow of rain waters—a proceeding to correct the evil by a single comprehensive scheme of improvement on lands in an improvement district which embraces a portion of all of the municipalities affected by the evil conditions is, as we have shown, more than a mere municipal affair.

Thus the court comes to the conclusion that the construction of a sewer and storm drain that serves territory in two cities is not a "municipal affair," but a "state affair," and that a city has no power to carry on such a project except pursuant to authority granted in specific statute, in this case the City Line Act.

This is practically the extent of the court decisions of this state that are applicable to the particular aspect of this problem. There is a very long series of statutes that provide for the organization of various types of sanitary districts. They provide generally for the Board of Supervisors or the City Council to call an election upon presentation of a petition of a certain per cent of the voters. They set up procedures that in most cases require the calling of elections and of a procedure expensive to carry out, and for practical purposes we cannot use them in small areas. There is, however, an act generally known as the Act of 1899, for taking care of this problem of relatively small areas adjacent to cities. This act provides that the Board of Supervisors may by resolution, upon petition of a certain per cent of the people within the particular area, create a sanitary district, and the sanitary district when created can contract, or rather the Board of Supervisors representing that district can contract, with the adjacent municipality for the disposal of the sewage in the adjacent area. The Board can levy a special tax upon the area benefited to construct the improvement, and when the improvement has been constructed, the Board can, by contract with the city, provide the terms and conditions under which the sewers constructed by the Board in the outside area can be connected with the city's sewer system.

I do not believe the City Council has the power to construct a sewer system beyond its corporate limits, or that it has any power to permit an outside area to connect its sewer system to the city system, except pursuant to the procedure set up by a specific statute granting such authority. I must tell you again, as I did in the beginning, this conclusion is my judgment; another lawyer may disagree with me; but I think that is the only conclusion you can draw from the statutes and decisions in this state. It is my own opinion that these decisions of the courts are sufficiently clear to indicate this conclusion.

Here is something else I intended to interpolate in the Black case. The court stated that in considering this question they assume:

> It may be that the power to maintain a sewer may carry by implication the additional power to levy a monthly charge to raise money for the repair and upkeep of such sewer. . . .
>
> A court cannot apportion the charge or ascertain and allow such portion as it might find reasonable assuming but not deciding that the city under its organic law is authorized to impose regular charges for such repairs and maintenance.

From that language I would say that the court was expressing some doubt as to the inherent power of a city to levy a sewer license, and it is possible that the cities of this state have no inherent authority to levy a license for the use of a sewer. At least the courts have not said

they have. It is my opinion, however, that when this question is squarely presented, the courts will hold that a city can exercise the function of collecting sewer licenses to operate and maintain a sewer system. However, the court in the Black case cast a very serious doubt upon that question.

Now, in conclusion, may I summarize. It is my opinion that:

1. Cities of the fifth and sixth class can levy a sewer rental fee for the purpose of operation and maintenance of the particular sewer. This conclusion is, however, subject to some doubt.

2. Cities of the fifth and sixth class cannot levy a sewer rental fee for revenue purposes.

3. Cities of the fifth and sixth class cannot levy a sewer rental fee for the purpose of extending a sewer system or for the construction of another sewer (see the Black case).

4. Charter cities that are generally empowered to construct public utilities can levy a sewer rental charge either for revenue or for operation and maintenance.

5. No city has the inherent power to construct a sewer beyond its boundaries for the benefit of adjacent territory.

6. No city has the power to permit adjacent territory to connect its sewers with the city sewers, except as such connection may be made pursuant to some specific statutory power.

ADMINISTRATION OF NEW YORK STATE REQUIREMENTS RELATIVE TO QUALIFICATIONS OF SEWAGE TREATMENT PLANT OPERATORS *

By Anselmo F. Dappert

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Section F, Chapter XI, of the New York State Sanitary Code, effective October 1, 1937, prescribes the qualifications of sewage treatment plant operators and the conditions under which appointments may be made. The regulations do not apply to operators employed by the City of New York or by private institutions or companies. They apply to operators who are paid from public funds, including subordinate personnel in sewage treatment plants.

In common with new regulations of this kind, they include a "grandfathers clause." Operators employed prior to October 1, 1937 or appointees from civil service lists established prior to this date are exempt, although these exemptions do not imply state approval of qualifications.

With these exceptions, appointments of operators not possessing the requisite qualifications at time of appointment, are prohibited. However, provision is made for the issuance of waivers in behalf of proposed operators who do not fully meet the requirements. Applications for waivers must be accompanied by a statement setting forth adequate reasons in support of such requests.

Qualifications are established for three grades of operators, dependent upon the size and kind of plants to be operated. The three grades are defined as follows:

Grade I Plants

(*a*) Serving more than 40,000 population.
(*b*) Serving 20,000 to 40,000, employing secondary treatment, separate sludge digestion, or chemical precipitation.
(*c*) Serving more than 10,000, employing activated sludge process.

Grade II Plants

(*a*) Serving 20,000 to 40,000, not designated as Grade I.
(*b*) Serving 10,000 to 20,000, employing secondary treatment, separate sludge digestion, or chemical precipitation.
(*c*) Serving less than 10,000, employing activated sludge process.
(*d*) Serving less than 5,000, employing gas collection, chemical precipitation, or activated sludge process.

* Presented at the Joint Meeting of the New York and New England Sewage Works Associations, Hartford, Conn., October 7, 1938.

GRADE III PLANTS

(*a*) Serving 5,000 to 10,000, not designated as Grade I or II.
(*b*) Serving less than 5,000, not designated as Grade II.

Subordinate operators acting under general supervision are required to possess qualifications one grade lower than the operators under whom they serve.

The qualifications established for the various grades offer in each instance three different possibilities for compliance. For each grade, three combinations of the three qualities of education, special training and experience are established as alternative specifications. At this juncture it is important to emphasize that in each case all three qualities are required and that experience alone cannot be substituted for special training, nor education for satisfactory experience.

In brief, the qualifications established for the various grades are as follows:

Grade I.

(*a*) Degree in public health, sanitary, chemical or civil engineering and one year of satisfactory experience in sewage treatment; (university or college courses must have included acceptable courses in sanitation) or

(*b*) Completion of a special course of training approved by the Public Health Council as qualifying for Grade I and two years of satisfactory experience (no educational requirement is specified, but education of applicants must be sufficient to permit admission to and passage of an approved special course) or

(*c*) Any combination of education, special training and experience which in the opinion of the Council is equivalent to either of the other two specifications.

Grade II.

(*a*) High school education, completion of a special course of training approved by the Public Health Council as qualifying for Grade II, and one year of satisfactory experience in sewage treatment; or

(*b*) Completion of an approved special course of training and two years of satisfactory experience (no educational requirement is specified but education of applicants must be sufficient to permit admission to and passage of the special course of instruction for operators in this grade) or

(*c*) Any combination of education, training, and experience acceptable to the Council as equivalent to either of the other two specifications.

Grade III.

(*a*) One year of satisfactory experience in sewage treatment (no educational requirement specified) or

(*b*) Completion of a special course of instruction approved by the

Public Health Council as qualifying for Grade III and 3 months of satisfactory experience in sewage treatment; or

(*c*) Any combination of education, training and experience acceptable to the Council as equivalent to either of the other two specifications.

With these provisions in mind, we may proceed to consideration of their application and some of the problems involved in the administration of the requirements.

Responsibility for the enforcement of the State Sanitary Code rests with local health officers and the State Department of Health. In this particular, because of the nature of the regulations, responsibility for their administration and enforcement rests largely with the State Department of Health. Although the Public Health Council is not an enforcing agency, through its regulatory and advisory powers it has much to do with the formulation of policies with respect to administration and enforcement of regulations enacted by it.

Under the regulations, anyone may submit qualifications to the Public Health Council for an opinion as to whether or not they meet the requirements, although the Council will not consider applications from residents of other states unless they have immediate prospects for employment as operators in New York State or for other special reasons. It is to be noted that the New York regulations do not provide for the licensing of operators but only for the approval of their qualifications. It is, however, anticipated that arrangements will be made soon for granting certificates of qualification to operators who have applied for and received approval.

Application blanks to be used in submitting qualifications for consideration of the Council may be obtained upon request from the State Department of Health. The Council meets once each month except during July and August and generally, in order to receive prompt consideration, applications must be on file by the middle of the month preceding the month of Council meeting. Action upon applications is frequently postponed to permit proper review of the applicants' statements.

It is a matter of much interest to consider how the regulations affect the status of existing sewage treatment plant operators. These greatly outnumber the new operators who are entering the field. Practically all of these existing operators were employed prior to October 1, 1937 and, therefore, do not come within the scope of the regulations. They may continue in their present positions without in any way having to meet the qualifications as prescribed. However, they may not be employed as operators in other plants unless they are qualified in the appropriate grade or secure a waiver of the requirements as applying to any proposed specific appointment. There is thus some considerable difference between exemption from the requirements and formal approval of their qualifications. Approval of qualifications connotes special recognition of an operator's competence and ability while an exemption does not. There is thus a desire on the part of operators, who

believe themselves to be qualified, to submit their qualifications for review and approval. To date the qualifications of twenty-two operators have been approved in Grade I, thirty-two in Grade II, and sixty-seven in Grade III. One waiver in Grade II and nine waivers in Grade III have been granted.

The existing operators, regardless of whether or not they are able to secure approval of qualifications in the grades represented by their plants, are enjoying a considerable degree of protection in their present positions as a result of the regulations. The objective of the regulations is, of course, to raise the general qualification level of plant operators to that required for the proper and satisfactory operation of plants. The regulations strike particularly at the practice of replacing competent operators with inexperienced men because of political considerations.

To illustrate the principle of the protection afforded, consider the case of a good operator, who, although not eligible for approval because he fails to meet the special course requirement, is nevertheless considered competent for the particular plant which he operates, and who is exempt under the "grandfathers clause." The position of such operator cannot be considered to be protected if the municipality desires to appoint an operator having the requisite qualifications. A municipality has a right to dispense with an operator's services at any time within the limits provided by local civil service or other regulations. As far as the Sanitary Code regulations are concerned, they do not prevent the "firing" of old operators, but they do govern the appointment of new ones.

It may be said, however, that unless political considerations are the motives there are few communities which would want to terminate the services of local operators who are rendering faithful and competent service in the performance of their work. And if political considerations comprise the motives for a change in operators, there is great probability that the person whom the municipality wishes to appoint will not possess the requisite qualifications or be able to obtain a waiver of the requirements.

In reviewing requests for waivers, the Public Health Council takes into consideration not only the preliminary qualifications of proposed operators, but the reasonableness of the circumstances offered in support of such requests. In view of the fact that the regulations are designed in part to terminate the appointment of operators for political reasons it goes almost without saying that requests for waivers dictated by political expediency will be denied.

In the event of an effort made to replace the services of a qualified or exempt operator, with an unqualified person, the operator himself could bring an action to restrain the municipality from making such appointment. In the last analysis he could not prevent the termination of his services but he could probably prevent the municipality from making an appointment in violation of the Sanitary Code. In the event such a case involved replacement of an operator having the

requisite qualifications it could be expected that the State Department of Health would intervene in his behalf. It would not intervene in a case involving replacement of a qualified operator with another qualified operator, nor in a case involving replacement of a poorly qualified exempt operator, except to the extent of requiring the new appointment to be made in line with the provisions of the Sanitary Code. In the case of an incompetent or unsatisfactory exempt operator whose services a municipality wishes to replace with a new operator, favorable consideration probably would be given by the Council to the granting of a waiver if such were necessary to effect a change and provided the proposed appointee possessed satisfactory preliminary qualifications.

It is thus apparent that the good operators who are rendering satisfactory service, even though they may not be able to qualify for approval at the moment in the grade represented by their plants, are receiving considerable protection in their present positions.

For the benefit of existing operators who are applying for approvals, a few features of the regulations and their application are in need of explanation and special emphasis. Appreciation of the philosophy back of the regulations, their general purpose, and the viewpoints with respect to their administration will soften the disappointment of many operators who have applied for and been refused approval of their qualifications in the grade represented by their present plants.

The prescribed qualifications for the three grades are fairly clear and within certain limits any operator should be able to measure himself against the requirements. Operators should not, therefore, try to secure approval in a grade above that in which they believe themselves to be qualified. Rather, they should consider the ways and means of improving themselves so that they may be approved in the desired grade. It should be remembered that the requirements are definite regulations which do not permit of any very flexible interpretation. The Public Health Council insists that the requirements be met before approvals are given.

As previously stated, approval of qualifications connotes recognition of the particular competency and ability of an operator to operate any kind or size of plant coming within the grade designated by the approval. It is at once recognized that an operator may be fully competent to operate a particular plant and have a creditable or enviable record of satisfactory experience and still not be able to secure approval in the grade represented by such plant. A case in point would be the operator of an Imhoff trickling-filter plant who lacks training or experience requisite to proper operation of an activated sludge plant. Operators who are denied approvals in the grades represented by their plants or positions should consider this feature of the regulations and by no means construe unfavorable action by the Public Health Council as a reflection upon their competence or abilities as operators of particular plants. There are many operators, who have been denied approvals in the grade applied for, whom the Department recognizes as particularly competent in their present positions.

Even though some operators may feel that the requirements are severe, it is in their own interests that the standards be maintained at a fairly high level. If they were lowered it would be much easier for municipalities acting through political expediency to find men with qualifications of a lower order to displace the services of existing operators.

As applying to operators of Grade III plants or in Grade III positions, applicants who are able to offer a year or more of satisfactory experience will receive approvals in this grade. Applicants for approval in Grade III, however, who lack experience will be advised as to provisions of the Code relating to waivers. Requests for waivers will not be considered unless the applicant has prospects for employment as an operator or unless the request is made or endorsed by the local appointing authority.

Waivers will not be granted unless the Public Health Council feels that the circumstances justify such action and that the proposed operator's preliminary qualifications are such as to give promise of ability to qualify within a short period of time. When waivers are granted in Grade III, as a general rule a stipulation will be made that the operator must attend and pass the next special course of instruction given and approved by the Council as qualifying for Grade III. Such courses are to be given at several universities in the state in odd numbered years, as a part of the general program of the Municipal Training Institute for the training of public personnel.

Such courses are of three days duration, instruction being given largely through lectures and demonstrations. Passage of an examination is a requisite for successful completion of the course. These courses will be given probably in April, 1939 in cooperation with New York University, Cornell University, and Rensselaer Polytechnic Institute.

With reference to Grade II, attention is called to the fact that the special course requirement is prescribed by all of the alternative specifications. The special course requirement applies to applicants who have a high school education as well as to those who do not. A high school graduate is given credit for only one year of experience over operators who lack such education. This special course is different from the course approved as qualifying for Grade III, and is designed to take an operator through fields of knowledge which lie generally beyond the comprehension of operators with education very much below the high school level.

These courses, approved as qualifying for Grade II will be of two weeks duration, and will be given by several universities in the state each two years. In 1940 it is probable that New York University, Cornell University and Rensselaer Polytechnic Institute will conduct such courses.

Experience alone is not accepted by the Council as a substitute for completion of the special course of instruction approved for Grade II, although experience which has included special training acceptable to

the Council as a satisfactory equivalent to the special course of instruction, may be offered as a substitute under the combination-equivalent specification. Operators who have received special tutoring or coaching under consultants or experts over a sufficient period of time and to a degree which can be considered equal to training which would be received in the special two weeks short course may be able to secure approval in Grade II without the necessity of taking any further special courses.

In this connection, however, it should be pointed out that to receive favorable consideration by the Council, special individual training of this kind must be a rather definite and methodical program of instruction which will give the operator a rather broad understanding of the fundamentals of the subject, operation practices, and laboratory procedures. It must be far more than conferences and talks about operating problems.

The general reason for the special course requirement is to assure that operators will have some fair understanding of processes and problems involved in the operation of various kinds of plants encompassed by the Grade II designation, and to give them at least a fair introduction to laboratory work with which operators in this grade should be familiar. It is believed that any operator possessing satisfactory experience qualifications who is able to complete this special training, is the kind of operator who safely can be entrusted with the care and operation of any Grade II plant.

The special course will open up for many operators a new enthusiasm for their work and desires for continued study which may extend for long periods into the future. No one would suggest, of course, that in two weeks time an operator could be taught all there is to know about sewage treatment. At best he can be given only a brief introduction to some fundamental subjects and a certain guidance on future efforts to improve his knowledge and understanding of sewage treatment.

Operators who regard themselves as competent and who meet both the educational and experience requirements for Grade II and yet are not eligible for approval in this grade may be inclined to feel that the special course requirement is an unnecessary imposition. A more reasonable view, however, is to consider that because of the requirement, existing operator positions are given better protection, and that eventual approval in Grade II being denied to no one, any operator willing to make real efforts to improve himself, can achieve such approval. Operators through their own initiative can prepare themselves for admittance to and passage of these special courses or can arrange with some one for equivalent private and individual instruction.

The granting of waivers in Grade II will be governed by the circumstances of the requests and the preliminary qualifications of proposed operators. It can reasonably be anticipated that proportionately fewer waivers will be granted in Grade II than in Grade III.

One governing principle in the granting of waivers may be taken as a requirement that proposed operators in whose behalf waivers are requested shall have education at the level indicated by the regulations. As a general rule, therefore, waivers in Grade II will be granted only to persons having a high school education or its equivalent.

With respect to Grade I, applicants who have engineering degrees, whose courses of study have included courses in sanitary engineering or sanitary chemistry and who have had one year of satisfactory experience, will be approved. Graduate engineers or persons with B.S. degrees whose academic courses have not included sanitary engineering subjects, but who have acquired in their experience, a knowledge of sewage treatment and familiarity with laboratory procedures, etc., sufficient to be considered by the Council as equivalent to the special training received by sanitary engineering graduates, will also be approved. Operators, however, who lack a college education, in addition to offering the very best in experience, must comply with the requirement of having completed a special course of instruction approved by the Council as qualifying for Grade I, or other special training equivalent to this, before they will receive approval in this grade.

Early this year, special courses approved by the Council as qualifying for both Grades I and II were given by New York and Cornell Universities. Instruction was gauged generally at a level somewhat higher than the Grade II level. Owing to the relatively high requirements established for successful completion of these courses, many of the 30 operators who attended failed, notwithstanding that several made very excellent progress considering their previous education and experience.

More would have been able to pass these courses if they had been approved as qualifying only for Grade II. One or two of these operators, lacking any academic college training but nevertheless offering outstanding experience in sewage treatment and having passed the special course with high averages, have been approved in Grade I. All who passed this course and meet the experience requirement will be approved in Grade II. And possibly one who failed to pass the course by a narrow margin but who offers a good record of experience will be approved in Grade II.

As a result of this experience in the direction of providing advanced training for sewage plant operators, it has been decided that in the future such courses will be approved only as qualifying for Grade II. No efforts will be made in the immediate future to establish any regular course for the purpose of qualifying operators for Grade I.

There is a great need for special courses to enable the advancement of good operators from Grade III to Grade II and this need must be given the primary consideration. There is not so much need for a special course to qualify for Grade I since the majority of operators who may be approved in Grade II do not possess education at the level required for Grade I, and except in unusual and exceptional cases, it would be impossible for such operators to pass an examination for Grade I.

In the immediate future, therefore, approved Grade II operators who are insistent upon going to the top must themselves arrange for a suitable course of instruction at some university extending over such period of time and covering such subjects as will meet the approval of the Council in individual instances.

Waivers in Grade I will be granted when the circumstances justify but it may be anticipated that almost without exception a waiver will not be granted unless the applicant possesses a college degree.

From the public health standpoint, the regulations have but one purpose and that is to secure competent and properly trained personnel in sewage treatment plants, and keep them there.

The regulations do not necessarily prevent the displacement of operators; a municipality acts within the provisions of the Sanitary Code whenever it appoints a qualified operator, regardless of whose services he may displace. But the displacement of good operators with unqualified operators is a practice which the regulations are designed to stop.

The regulations have been in force for only a year and based upon experience thus far, it is apparent that they are having their desired effect. In a few cases where changes in operating personnel were threatened a warning from the Department has served the good purpose of retaining the present operator in service. For the most part municipalities have shown an encouraging desire to comply with the provisions of the code in respect to new appointments. There are probably few municipal officials having the power to fire or hire operators who would care to be publicly cited for violation of the Sanitary Code by appointment of unqualified operators to replace the services of competent men. But aside from this consideration, it has been apparent in recent years that municipal officials generally appreciate the necessity of providing competent persons for technical positions, and would be reluctant to displace the services of operators who have gained some reputation for doing their work well.

Some attempts have been made to circumvent the spirit and intent of the regulations and in one instance the "grandfather clause" has operated so as to permit the replacement of a qualified Grade II operator serving in a Grade III plant under very general and questionable supervision of a superintendent, with an operator able to meet only the preliminary qualifications established in the regulations.

However, with the passage of time it is expected that difficulties of this kind will disappear altogether and that all municipal officials and operators will accept reasonable administration and enforcement of the regulations as being in their mutual interests.

In New York State, we must accept the view that the large majority of present operators are giving excellent attention to their plants and should be continued in their positions. The New York State Sewage Works Association has done much to inspire operators to improve their abilities and has provided a stimulus for many of the activities carried on to raise their standing. As a group they have shown an

amazing desire not only to serve the public faithfully but to acquire knowledge and instruction which would better fit them for their duties. As long as this condition prevails there is assurance that the sewage treatment plants under their charge will continue to show improvement in the economy and efficiency of their operation.

There is thus every reason for continuation of the services of good operators regardless of whether or not at the moment they measure up fully to the fairly high standards prescribed in the Code. The backlog of experience represented by these operators is something too valuable to lose.

With respect to new appointments, the main interest is in securing operators who preferably either have the requisite qualifications or who are capable of developing rapidly into competent and reliable operators. The waiver is a necessary instrument essential at least for the admission of promising talent to the field, and whenever it is employed, it will be used with discretion and with this thought in mind.

As new plants are constructed or as vacancies occur in existing plants, the general effect of the regulations will be to secure appointment of qualified operators. This will come about rapidly as far as operators of new plants are concerned, and gradually with respect to replacements made necessary through deaths. The new plants, therefore, will be under the charge of operators with better education and initial training than has prevailed in the past, and over a period of years the general qualification level of the operators as a group will have advanced considerably.

In conclusion it is perhaps significant to remark that " at long last " sewage treatment plant operators in New York State are now classified in the Sanitary Code as public health personnel and, in principle, the same kind of recognition has been accorded them as has been given to local health officers and public health nurses. This in some measure reflects the opinions which prevail with reference to the responsibilities of sewage works operators and should be a challenge for many operators to advance themselves in public esteem through rising to the highest possible achievements in the field.

Discussion by W. J. Scott

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The New York State law appears to be very similar to the law which was passed in Connecticut in 1933 and which provides that the qualifications of operators of sewage treatment plants shall be subject to the approval of the State Department of Health. As a result of the passage of the Connecticut law, the Public Health Council adopted rules and regulations concerning qualifications of operators of sewage treatment plants.

The Connecticut requirements are somewhat different from those in New York in that they do not establish any grades for various sizes and types of plants, although specific requirements are covered in the

rules and regulations. Since our law went into effect, there has been no replacement of well-trained and experienced operators. In two or three instances local officials have considered replacements but have finally come to the conclusion that they would leave well enough alone. The fact that replacements can be made only with qualified men tends to discourage political manipulations.

It is difficult to evaluate the relative merits of education, training and experience. Each plant is somewhat of a problem in itself. In mechanized plants the value of mechanical training and of experience cannot be overemphasized. In large plants, experience in handling and direction of men is of the utmost importance. In the case of large mechanized plants, better operating results will usually be obtained with an experienced mechanical superintendent in charge of the plant. The difficulty in getting a man of this type with sufficient training along chemical lines may necessitate the employment of an assistant who is a qualified chemist. Short schools and conferences with sewage plant operators are highly desirable in making up deficiencies of chemical training and knowledge.

Neither the New York law nor the Connecticut law definitely guarantees tenure of office for sewage plant operators. However, as already mentioned, the fact that replacements must be made from the ranks of qualified men tends to promote a degree of civil service. The fact must not be lost sight of, that while the state has a very definite interest in seeing that plant operating results are satisfactory, the plant is municipally owned and it is absolutely necessary that there be cooperation between the sewage plant operator and the municipal government. The most qualified operator in the world cannot do a first-class job in the face of constant lack of cooperation by the municipal finance body and other municipal agencies. This brings us to the fact that the operator has a definite job in selling the value of his services to the municipality, which can best be done by conscientious operation, cooperation with supervisory authorities and constant effort to better his knowledge of sewage treatment by keeping up with developments, by contacts with other plants and other operators, and demonstration of initiative in undertaking plant betterments.

ACTIVATED SLUDGE—THE CASE FOR AIR DIFFUSION *

By Frank C. Roe

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A discussion of activated sludge treatment by air diffusion versus mechanical aeration, at first thought creates some speculation as to what the ensuing argument may be. Not so long ago the topic had reached the point of factional dispute in England. There the relative merits of oxygen absorption from air bubbles versus absorption from the atmosphere at tank surfaces, developed a most heated discussion. Many papers were written, supported by extensive data, on both sides of this question.

If it were possible to present a proof, obvious to everyone, that only one method has basic merit and that the other should be discarded, it is believed that such a proof would be well known by this time. On the contrary, one cannot deny that a good measure of satisfactory results have been secured by both mechanical aeration and air diffusion plants. The selection of either method should, therefore, be based upon economic and practical considerations. It is apparent that a good many engineers in this country have followed that principle.

There are now almost 200 diffused air plants, approximately 20 combined mechanical and air diffusion plants, and probably 100 mechanical aeration plants, providing activated sludge treatment in the United States. Based on the assumption that each method can show meritorious use, the writer sent out 100 questionnaires to a representative group of these plants. Returns were secured from 16 mechanical aeration plants, 5 plants combining mechanical aeration with air diffusion, and 20 air diffusion plants. While this was practically a 40 per cent return on questionnaires, the data are representative of approximately 13 per cent of the existing American plants. The essential data obtained are given in Table I.

There is a wide variation of figures on plants of similar capacity, as would be expected, supporting a universal belief that each sewage treatment problem has its own solution and that no general conclusions can be drawn. The data have been correlated, however, to form the principal theme of this study, which is an attempt to illustrate graphically the apparent optimum economical range of application of air diffusion plants as compared to mechanical aeration plants. Since many of the points plotted were quite remote from the mean curves drawn, it is suggested that another person might show slightly different slopes. Also, some of the data are based on estimates or short period tests and as such should be discounted. In spite of the difficulties mentioned, it is believed that the analysis is reasonably representative and correct.

* Presented at the Tenth Annual Conference of the Pennsylvania Sewage Works Association, State College, June 9, 1938.

TABLE I.—*Operating and Plant Cost Data.*

A—Diffused Air Plants, C—Combined Mechanical and Diffused Air Plants, M—Mechanical Aeration Plants.

	Type of Plant	Sewage Flow Treated M.G.D.	B.O.D. Reduction by Aeration P.P.M.	Lbs. B.O.D. Removed/ Day by Aeration	KWHrs./ Day Consumed by Aeration	KWHrs. per Lb. B.O.D. Removed by Aeration	Design Capacity M.G.D.	Total Plant Cost Thousands of Dollars	Total Plant Cost per M.G.D. (Thousands of $)
Sioux Falls, S. D.	A	4.5	176.4	6620	2420	.366	4.5	250	55
Chicago, Ill. (N. Side)	A	199.5	97.9	162600	45400	.279	—	—	—
Hillsboro, Oregon	A	.4	129	430	134	.316	.35	50	143
Springfield, Ill.	A	8.7	132	9570	2360	.247	7.5	600	80
Bartlesville, Okla.	A	.6	87*	435	269	.617	1.5	130	87
Hagerstown, Md.	A	3.0	158	3950	1720	.435	6.	330	55
Lancaster, Pa.	A	3.6	73	2190	1625	.743	6.	416	69
Gastonia, N. C.	A	1.2	161	1610	937	.582	1.6	180	112
U. S. Hospital, Ky.	A	.18	175	263	194	.737	.3	90	300
Berea, Ky.	A	.157	162	212	331	1.56	.17	30	176
Grand Island, Nebr.	A	2.0	160	2666	716	.268	3.75	124	33
Lima, Ohio	A	5.0	88	3670	2326	.634	9.0	630	70
Rockville Center, N. Y.	A	2.0	119	1981	—	—	2.0	450	225
High Point, N. C.	A	1.0	159	1325	1343	1.01	2.0	270	135
Tenafly, N. J.	A	1.06	80*	708	464	.655	.75	250	334
Bernardsville, N. J.	A	.183	175	268	48.5	.181	.5	69	138
Madison, Wis.	A	5.5	172	7880	3450	.438	6.25	500	80
Chatham, N. J.	A	1.82	108.5	1645	865	.525	2.0	190	95
Austin, Texas	A	3.65	202	6130	2347	.382	6.0	500	83
Waco, Texas	A	3.8	110	3480	2550	.733	5.0	198	40
Muskegon Hts., Mich.	C	1.37	131.3	1408	491	.348	1.5	105	70

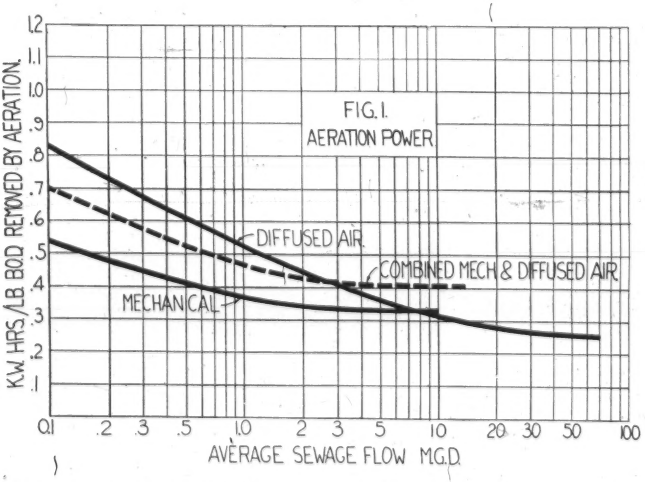
TABLE I.—(*Continued*).

	Type of Plant	Sewage Flow Treated M.G.D.	B.O.D. Reduction by Aeration P.P.M.	Lbs. B.O.D. Removed/ Day by Aeration	KWHrs./ Day Consumed by Aerators	KWHrs. per Lb. B.O.D. Removed by Aeration	Design Capacity M.G.D.	Total Plant Cost Thousands of Dollars	Total Plant Cost per M.G.D. (Thousands of $)
Mansfield, Ohio	C	3.5	93.9	2740	1165	.425	4.5	330	73
Jackson, Michigan	C	7.5	87	5440	4292	.785	11.75	700	60
Escanaba, Michigan	C	.75	135	844	363	.431	1.5	215	143
Phoenix, Ariz.	C	11.25	127.5	11950	5349	.447	12.	500	42
Harlem, N. Y.	M	.500	095	395	248	.627	1.2	213	177
Rochelle, Ill.	M	.326	206	557	340	.61	.8	112	140
Dane County Asylum, Wis.	M	.042	275	96	62.5	.651	.075	14	187
Mitchell, S. D.	M	.5	187.5	781	215	.275	1.2	110	92
Geneva, Ill.	M	.7	15.8	920	193	.210	.9	110	122
Flora, Ill.	M	.16	205.2	273	161	.589	—	—	—
Woodstock, Ill.	M	.733	100*	605	189	.312	.8	75	94
Princeton, Ill.	M	.488	67*	273	136	.498	.4	50	125
Christopher, Ill.	M	.38	73*	231	111	.480	.4	36	90
Buhl, Minn.	M	.36	182*	546	112	.205	.4	38	95
Batavia, Ill.	M	.611	178	908	200	.220	.7	85	121
Waverly, Ia.	M	.420	177*	618	251	.407	.4	70	175
Libertyville, Ill.	M	.106	223	197	89	.452	—	—	—
Chelsea, Michigan	M	.150	156*	195	63	.323	.25	60	240
Clintonville, Wis.	M	.305	97	246	166	.674	—	—	—
Elmhurst, Ill.	M	2.00	85	1415	700	.495	5.0	300	60
Collingswood, N. J.	M	.5	294	1225	670	.547	—	—	—

* Estimated.

In developing Fig. 1 it was decided to use "kilowatt hours per pound of B.O.D. removed by aeration" as the yardstick to measure aeration power, this being the principal item of operation cost of activated sludge plants. This unit was suggested and adopted by engineers of the Illinois Department of Health and was discussed by Messrs. Wisely and Klassen of that department in *Engineering News-Record* for September 10, 1936. The unit offered by Calvert and Bloodgood in Vol. VI, *Sewage Works Journal,* which is "dollars per thousand pounds of B.O.D. removed," is equally satisfactory as a measurement of work done, but it involves a little more calculation for the plant operators.

There can be little objection to the " work done " unit of measurement. As an incidental theme of this paper, its universal adoption is therefore suggested. Conditions in some places require a greater B.O.D. reduction than in other places and more power is naturally consumed in obtaining the greater reduction. The "work done" unit of kilowatt hours per pound of B.O.D. removed by aerators, gives due credit for the greater reduction, whereas, "kilowatt hours per million gallons" or "horse power per million gallons daily capacity," do not give credit and are misleading.

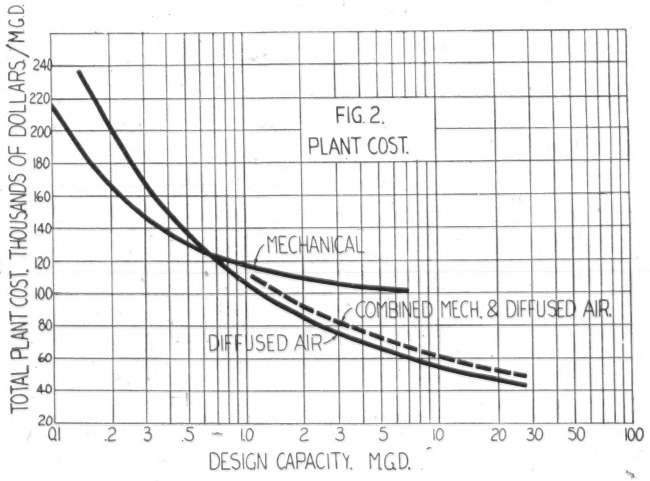


Referring to Fig. 1, it will be noted that the curve of power consumption for air diffusion plants lies above that for mechanical aeration plants up to approximately 7 M.G.D. It should be stated parenthetically that most of the data on the air diffusion plants were obtained direct from superintendents and were based on figures for yearly operation, while the data on the mechanical aeration plants had to be obtained for the most part from aerator manufacturers. This is due to the fact that most of the smaller mechanical plants are not equipped to run

B.O.D.'s and some do not have accurate flow measurement. The data obtained were, therefore, based on analyses and measurements of a month or less by the aerator manufacturers or by State Engineers.

Only one data card was obtained for a mechanical aeration plant above 1 M.G.D. capacity. This gave a power consumption point considerably above the curve. It is ridiculous to assume, of course, that the curve turns up again beyond 1 M.G.D. It does suggest to the writer, however, that he may have been over zealous in trying to avoid a natural prejudice in favor of air diffusion. As previously stated, most of the other data on smaller mechanical plants were based on short period tests. Yearly results might show that the actual curves are not so far apart.

While the curve representing combined air diffusion and mechanical aeration plants is based on relatively few data, its position appears consistent with the other curves. Perhaps there will be some criticism or suggestion that the curves do not flatten out completely at the higher flows as indicated. This may be true but they are the best the writer could develop from the data available.



The data from which Fig. 2 has been prepared are more reliable. At the same time, they are misleading because we all know how widely the original cost of a plant may vary depending on architectural embellishment, auxiliary equipment, method of sludge disposal, and numerous other factors. While some of the plotted points were again quite remote from the curve as shown, it is believed that a reasonable average has been struck.

In order to correlate Fig. 1 and Fig. 2 a third chart is necessary.

This is really the key to indicate the optimum range of capacity below which mechanical aeration appears favorable and above which air diffusion appears favorable. The difference in cost of plants is the most important factor affecting such a correlation. There are several other minor factors, most of which are too involved even to estimate and some of which are compensating. This important difference in plant cost has, therefore, been transformed to an interest saving (or expenditure) value which, in turn, has been evaluated as a decrease (or increase) of power consumption of air diffusion as compared to mechanical aeration.

To explain in detail, the indicated differences in plant cost on Fig. 2 were multiplied by .05 as an assumed rate of interest to give yearly differences of increased or decreased operating expense of diffused air plants over mechanical aeration plants. These amounts were transformed to a daily basis and converted to kilowatt hours based on an assumed rate of $0.01 per kilowatt hour. The air diffusion curve on Fig. 1 was then modified to reflect this equivalent increase in power consumption below 0.65 M.G.D. capacity (where the plant cost curves intersect), and the equivalent decreases in power consumption for capacities above 0.65 M.G.D.

TABLE II.—*Conversion of Difference in Plant Cost to Power Consumption Units*

Capacity M. G. D.	Total Difference in Plant Cost—Dollars	Yearly Interest at 5%	Daily Interest	KWHrs./Day at $.01 *	Hypothetical Change in Power Consumption; KWHrs./lb. of B.O.D. Removed by Aeration	
					Increase	Decrease
		Dollars	Dollars			
0.3	− 6600	− 330	− 0.90	− 90	.271	—
0.5	− 2250	− 112	− .31	− 30	.071	—
0.65	0	—	—	—	—	—
1.0	+ 11000	+ 550	+ 1.51	+ 151	—	.139
2.0	+ 48000	+2400	+ 6.60	+ 660	—	.325
5.0	+192000	+9600	+26.40	+2640	—	.400

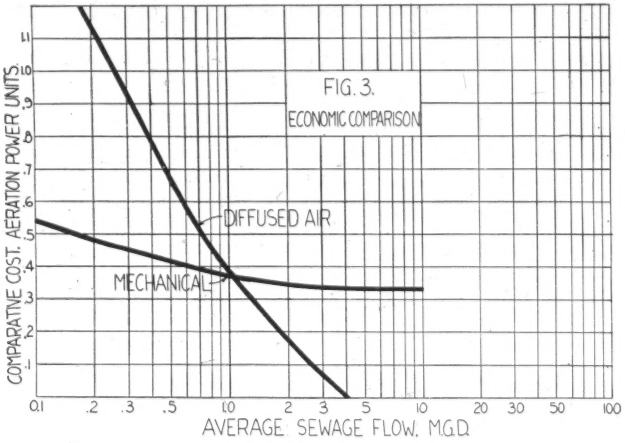
* These figures used to modify results in Col. 5 of Table I for diffused air plants of approximate capacities listed, to determine points for hypothetical economic comparison curve.

Table II provides a further explanation of this calculation. It will be noted that the theoretical decrease in power consumption for plants of 5 M.G.D. and larger is greater than the actual power consumption of such plants. This explains why the air diffusion power curve on Fig. 3 falls below 0 at 4 M.G.D.

On Fig. 3 this hypothetical air diffusion power curve now crosses the unaltered mechanical aeration curve at approximately 1.0 M.G.D. It would thus appear that on an economy basis alone, mechanical aeration plants are in the most favorable position below 1.0 M.G.D. and that air diffusion plants have the best chance above that point.

An additional important factor affecting economy should be con-

sidered, which is that of gas engines operating on digester gas. The engine-blower type of installation is considerably less expensive than the engine-generator-motors type of installation, especially for small



plants. Data are not available and the writer does not feel capable of estimating how much this factor would influence the point of intersection of the two curves on Fig. 3. The influence may be slight but if anything it would indicate a lower point above which air diffusion appears favorable.

This argument is supposed to present the case for air diffusion, but we started out by admitting "a place in the sun" for mechanical aeration. There are other important factors beyond that of economy to be considered, however, in developing the selection of method. Flexibility is one of these important factors.

Engineers universally recognize the soundness of graduated or tapered aeration whereby the first stage receives more air corresponding to its higher oxygen demand, than the later stages of aeration. It is obvious that this demand varies daily, with the seasons and from year to year. It is equally obvious that with air diffusion more or less air can be applied to any portion of the aeration tank by extremely simple control. No doubt a whole paper could be written to illustrate the economic and practical advantages of this flexibility.

It may be claimed that air diffusion plants require higher salaried operators than mechanical aeration plants. This may be so but, if so, the writer claims this as an advantage of air diffusion plants rather than a disadvantage. Sewage treatment is here to stay as an important function of municipalities. Investments which run into thousands and millions should certainly be entrusted to the hands of capable and re-

sponsible men who can command a proper salary. This principle has been generally proved to pay dividends in water works operation. Why then is it not true for sewage plant operation?

"Normal domestic sewage" is becoming more and more of a rarity in a true sense of the term. In analyzing the remarks offered with the data received for this paper, it was noted that the mechanical aeration plants giving satisfactory results are treating essentially domestic sewage. Where appreciable trade wastes are encountered, it appears that air diffusion will generally effect greater B.O.D reduction than mechanical aeration. This point, which is claimed as an advantage of air diffusion, has been indicated in at least two places where air diffusion was added after mechanical aeration failed to give sufficient B.O.D. reduction. In both cases, fluctuation from normal domestic sewage to strong sewage containing trade wastes could not be handled. Incidentally, these instances illustrate the advantage of flexibility.

There may be other factors not mentioned which have a bearing on selection of method, such as character of sludge developed by each method and the respective cost of disposal. These can be important but the advantages or disadvantages are controversial, with insufficient data to substantiate a definite claim.

To conclude, it is suggested that the curves offered as a comparison of economy of the two basic methods of activated sludge treatment be considered as something to "shoot at." This is intended to have a double meaning. In the first place, it is admitted that a *complete* assembly of reliable data from all existing plants might enable one to "shoot holes" into these curves. The moral is, let us have more and better operating data on all plants. (The writer gladly volunteers to serve as a clearing house to correlate and record reliable data.) Secondly, assuming the curves may be reasonably correct for averages, they will provide a goal for some engineers and operators to shoot at or under and thereby ultimately lower costs of construction and operation. This will naturally benefit all.

When and if curves of the nature illustrated are substantiated by reliable data from a majority of our plants, such curves may serve as a valuable guide. No basic change of general opinion is likely because it is a matter of record that the design capacity of both types of plants built to date has been for the most part, within the indicated optimum ranges. The guide would be of help, however, on border line cases since the trends of cost in either direction would be indicated.

In closing, the writer wishes to acknowledge with appreciation the cooperation of the many plant superintendents and chemists who so kindly provided the data which have made this study possible. The assistance of all manufacturers of mechanical aerators, who provided much of the needed data on that equipment, is also gratefully acknowledged.

RESUMÉ OF OPERATING EXPERIENCE OF MECHANICAL SURFACE AERATION *

By S. E. Kappe

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The successful operation of an activated sludge plant is dependent upon oxygenation capacity to maintain aerobic conditions necessary for the existence of the organisms that perform the work of purification. This oxygen is generally introduced by compressed air or mechanical surface aeration.

Compressed air aeration, commonly called "diffused air," is accomplished by diffusing air under pressure through plates or tubes. The oxygen is available from the diffused air bubbles and from surface circulation.

Mechanical surface aeration employs the use of circulating pumping devices or revolving brushes and paddles to introduce air from the atmosphere into the mixed liquor. The majority of existing mechanical surface aeration plants are of the circulating pumping device type. Some pumping devices introduce air by discharging sheets of the liquor into the atmosphere, aided by violent surface agitation. Other pumping devices draw air bubbles into the liquor being circulated.

Subsequent reference to mechanical aeration throughout this paper refers only to mechanical aeration of the circulating pumping device type, unless otherwise stated.

For the purpose of comparison of mechanical surface aeration vs. compressed air, this paper presents a discussion on mechanical surface aeration based upon the following factors: (1) Aeration Tank Capacity (2) Aeration Equipment (3) Oxygenation Capacity (4) Operation (5) Power Consumption (6) Cost of Construction.

It should be borne in mind that every sewage treatment plant situation is different. It is a separate problem and must be analyzed in the light of prevailing local conditions. The design, operation and costs of construction and operation are affected by such factors as sewage and flow characteristics, degree of treatment required and produced, intermittent and seasonal discharges of cannery and industrial wastes, raw sewage and sludge, odor control, amount and type of mechanical equipment provided, and flexibility in plant layout.

Aeration Tank Capacity.—The size, shape and number of mechanical surface aeration tanks depend upon the quantity and character of sewage, aeration period, percentage of return sludge and the selection of proper aerating mechanism. The aerator must have sufficient oxygenation capacity to satisfy the oxygen demand and sufficient circulation capacity to mix thoroughly and keep in continuous contact

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and suspension the impurities in the sewage and the coagulating-adsorbing activated sludge.

Aeration tank capacities are generally based on average daily flows to provide an aeration period dependent upon the strength and amenability to treatment of the sewage. Generally 6 to 8 hours is required for normal domestic sewages and longer periods for stronger sewages.

The tanks are generally square or round, with flat or hoppered bottoms. Most mechanical surface aerators give satisfactory results in either flat or hoppered bottom tanks. The largest known, successfully operating, aeration tanks have a capacity of approximately 95,000 gallons each. These tanks are 36 ft. square by 16 ft. water depth. Aeration tanks have been used with surface areas varying from a minimum of 16 ft. square to a maximum of 36 ft. square, with water depths varying from a minimum of 9 ft. to a maximum of 19 ft. Where the presence of rock or ground water dictates shallow tanks for construction economy, water depths as low as 7 ft. may be permissible. Aeration batteries with tanks over 65,000 gallons capacity have been found to be inflexible and require excessive power for circulation over and above the oxygenation required. Tank capacities averaging about 50,000 gallons afford maximum flexibility and economy in power consumption for circulation and oxygenation.

The design of the aeration battery should provide for separate, walled-off tanks for each aeration unit in order to secure maximum economy and flexibility in operation. There may be times, seasonal or otherwise, when the incoming sewage will have a high immediate oxygen demand. The tank arrangement should be flexible to permit pre-aeration of the raw or settled sewage at such times, if necessary. Provisions should be made to allow the return activated sludge to be mixed with the sewage after it had been pre-aerated.

Channels and openings between aeration tanks should be designed to avoid undesirable head losses and to reduce to a minimum sewage level fluctuations in the aeration tanks. Maximum flow rates have been observed to cause fluctuations up to one foot. Excessive fluctuations are detrimental because the efficiency of most mechanical aerators is materially affected by fluctuation over 1 or 2 inches.

Aeration Equipment.—The selection of the size of aeration equipment for adequate oxygenation capacity and adequate mixing capacity should not be based on what has worked satisfactorily at another plant because appearance is deceiving and no two sewages have the same treatability characteristics. The selection of proper size equipment is dependent upon sewage strength, character, rates of flow, and the aeration tank capacities being provided.

Manufacturers of mechanical aerators recommend a minimum of 3 complete tank turnovers per hour, depending on the strength and character of sewage under treatment. The writer's own Company recognized the fact that an important correlation existed between turnovers and oxygenation capacity. To take advantage of this phenomenon, the Company made available aerator propellers with circulation capacities

ranging from 1000 to 7500 gal. per min., to provide any desired number of tank turnovers per hour. The aerator is rated at supplying 6.0 p.p.m. of oxygen to the mixed liquor per turnover. This gives an indication of the flexibility in the selection and design of aerators to meet requirements.

The aeration equipment itself should have ruggedness, simplicity, and a minimum amount of mechanism, to keep down maintenance and upkeep costs. The design of the equipment should be such as to preclude the possibility of clogging, freezing, or formation of frazil ice. Ice formation or clogging may stop the aerators or reduce the effectiveness of aeration considerably by causing lower rates of recirculation and clogging of aerator parts. The aerators should not allow scum to form on the surface of the aeration tanks. Floating scum reduces surface aeration, induces septicization, and robs the sludge of life-sustaining oxygen.

The aeration equipment should be capable of sustaining high bottom velocities. Deposition of sludge on the bottom of tanks and in corners is detrimental to the activated sludge process. Minimum bottom velocities of 0.5 to 1.0 ft. per sec. are desirable to maintain the sludge in suspension, particularly in flat-bottom tanks. High rates of circulation insure thorough mixing and continuous contact between the impurities in solution and suspension in the sewage, and the clarifying and stabilizing activated sludge.

During the first stage of the aeration period the finely divided and dissolved solids in the sewage are rapidly clarified and stabilized. Studies indicate that under proper operating conditions from 70 to 80 per cent of the total purification takes place in the first hour of aeration. During this period the rate of oxygen utilization (1) is at a maximum, persisting uniformly for a time proportional to the strength of the sewage. The rate of oxygen utilization then drops sharply, and subsequently more slowly, until a point is reached where good purification and a well activated sludge is obtained.

The aerators used during the first hour of aeration should have sufficient oxygenation capacity to meet the demand. If the aerator employed has a relatively low oxygenation capacity, the sludge activity will be limited and a longer aeration period will be required to produce good purification and a well-activated sludge. The oxygenation capacity of the succeeding aerators can be reduced to fit the rate of oxygen demand throughout the purification period. The rate of oxygen supply required can be determined by the Odeeometer or chemical demand tests, or estimated for normal sewages from theoretical formulae and data collected from tests on various sewages.

Oxygenation Capacity.—There has been much discussion in the past by various investigators as to whether most of the oxygen is absorbed from air bubbles rising through the liquid, or from the atmosphere at the liquid surface.

Arguments have been presented in favor of both, but a review of the literature indicates that most investigators believe most of the

oxygen is absorbed at the liquid surface rather than from the rising bubbles.

This phenomenon is thought to be caused by the colloidal matter in sewage. The bubbles rising through the liquid are believed to become covered in a colloidal and surface tension film which interferes with the passage and absorption of oxygen until the bubbles break at the surface of the liquid. Freese's (2) studies substantiate this theory. They indicated that air and an inert gas—nitrogen—gave practically the same purification results, and that a large part of the oxygenation occurs as the bubbles break at the surface of the liquid. Babbitt (3) points out that in mechanical surface aeration plants, sewage exposed to the air in sheets with a high rate of circulation allows a constantly changing layer of unsaturated liquor to be exposed to the air and become almost instantaneously saturated with oxygen. Babbitt states that this turning over and exposure to the air is essential regardless how it is accomplished, and as evidence of its importance refers to the greater success of spiral-flow tanks over ridge-and-furrow tanks. Roe (4) reports that the spiral-flow type of tank requires 25 per cent less air than the ridge-and-furrow type. The research engineers of the writer's Company found during their early studies in 1932 that if a stoppered bottle, three-fourths full of distilled water, was gently inverted and returned to its original position there was an increase of dissolved oxygen content in the water as high as 60 per cent.

It appears from the results of various investigators that oxygenation capacity depends on good circulation and continuous exposure of thin films of sewage breaking at the liquid surface. With mechanical surface aerators it was found that the aerator furnished should have a minimum circulation capacity of about three turnovers per hour for normal domestic sewages. The maximum rate of circulation of mechanical aerators is, however, limited by hydraulic laws and economical factors to about eight turnovers per hour, while compressed air aeration of the spiral-flow design allows much higher rates of circulation. Apparently due to these conditions, for economical operation, the rate of oxygenation is limited for mechanical aerators and is lower than for compressed air.

Mechanical aerators have satisfactorily treated raw sewages having an average B.O.D. as high as 600 p.p.m., which indicates that mechanical aerators are available which have adequate oxygenation capacity to treat economically normal sewages, and abnormal sewages. The highest rate of oxygenation capacity kown to be installed for mechanical aerators is at Monroe, Wisconsin, with 7½ HP. "Chicago" aerators, in a 45,000 gallon capacity tank, which supply an oxygenation capacity of from 60 to 70 p.p.m. per hour. At Monroe the aerators, ranging in size from 7½ to 2 HP., are able to treat satisfactorily a sewage changing momentarily in B.O.D. from 90 to 1100 p.p.m., with a 10-hour aeration period.

The activity, or roughly the amount of sludge which can be carried in the aeration tanks, is generally limited by the rate of oxygen that

can be supplied at the inlet end of the process. If a higher sludge activity can be maintained with any given sewage, the aeration period can be reduced. Since compressed air, because of its higher rate of oxygenation, allows a higher activity to be maintained, shorter aeration periods can be used than is usually permissible with mechanical aeration. This theory, however, does not hold true at all times. Some sewages, particularly those containing certain industrial wastes, differ in treatability characteristics. These sewages are observed to have a high immediate oxygen demand, which does not taper off so rapidly as normal domestic sewages and requires a much longer aeration period. Limited studies indicated that the aeration period with compressed air diffusion would not be much shorter, if any, than with mechanical surface aeration. This condition can be illustrated by the operation of an existing mechanical aeration plant.

During the year 1937 this plant treated an average flow of approximately 0.792 m.g.d. of domestic sewage. With the exception of two months of the year, the sewage had a 5-day B.O.D. of 175 p.p.m. and a suspended solids content of 176 p.p.m. An aeration period of 7 hours produced an effluent having a B.O.D. of 6 p.p.m. and a suspended solids content of 7 p.p.m. During two months of the year, this plant received an additional flow of approximately 0.25 m.g.d. of partially pre-treated cannery wastes from peas and corn, which increased the B.O.D. of 24-hour composite samples of the raw sewage to about 500 p.p.m., with daily peaks as high as 800 p.p.m. The existing 3 HP. aerators were found inadequate at such times and an investigation was made to determine whether the substitution of 7½ HP. aerators would provide adequate oxygenation capacity. These tests, accompanied by rate of oxygen utilization curves, showed that the maximum sludge activity which could be supported by mechanical aerators—approximately 60 to 70 p.p.m. of oxygen per hour—lasted over 5 hours before the curve dropped to its parabolic form and that the sewage would require an aeration period of from 16 to 18 hours. The aeration period available was only 8 hours, which was inadequate. Studies with compressed air diffusion with solids concentrations varying up to 2000 p.p.m. indicated that the aeration period could not be reduced to less than about 16 hours. This illustrates a case where what was in the B.O.D. was more of a factor than the actual amount of B.O.D.

Figure 1 illustrates two oxygen demand curves. Curve A indicates the oxygen demand characteristics of normal domestic sewages when an adequate supply of oxygen and an adequate aeration period are available. Curve B shows the oxygen demand characteristics when treating combined domestic sewages and pre-treated cannery wastes when an inadequate oxygenation capacity and inadequate aeration period are available.

Operation.—The two most important points in the operation of an activated sludge plant, regardless of whether it be of the compressed air or mechanical surface aeration plant, is first to maintain the proper amount of activated sludge in the mixed liquor and second to give the

activated sludge enough oxygen to keep the sludge alive and at its maximum activity. Mechanical aeration plants generally carry from 300 to 1000 p.p.m. suspended solids. An excess of dissolved oxygen, preferably 1.0 p.p.m., should be carried throughout each aeration tank. Operation records indicate that from 20 to 40 per cent of the activated

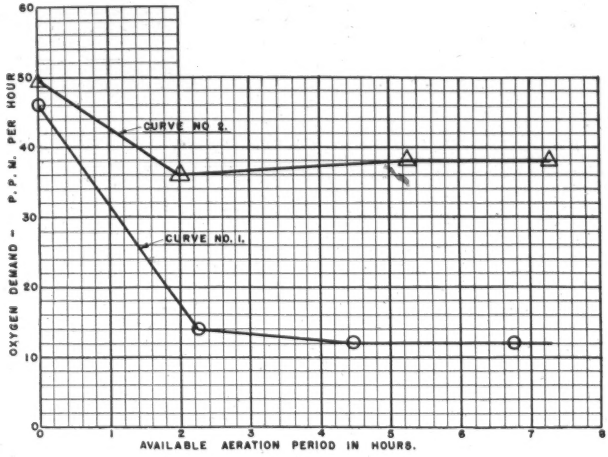

FIG. 1.—Curve No. 1 shows adequate oxygen capacity and adequate aeration period to meet the oxygen demand when treating normal domestic sewage.
Curve No. 2 shows inadequate oxygen capacity and inadequate aeration period to meet oxygen demand when treating combined domestic sewage and pretreated cannery wastes.

sludge is returned to the aeration tanks and that mechanical aeration plants produce from 1 to 3 per cent of combined primary and waste activated sludge. Proper control of the return sludge is important.

Existing plants being properly operated are producing effluents showing an average reduction of at least 90 per cent in B.O.D. and suspended solids of the primary effluents.

Power Consumption.—Separate current meters should be provided to measure the energy delivered to the aerators. Without them the power guarantees being made today by manufacturers, generally on a basis of KWH. per pound of B.O.D. removed, rather than the horsepower per million gallons, cannot be checked. A study of recent guarantees indicate that most manufacturers have been offering a minimum power consumption of 0.35 KWH. per pound of 5-day B.O.D. removed by aeration, or 18 HP. per m.g.d. when treating fresh domestic sewage, with 200 p.p.m. B.O.D. Operation results generally indicate that the KWH. per pound of B.O.D. removed are lower for higher strength sewages and higher for lower strength sewages, and that HP. per m.g.d. is low during wet seasons and high flows, and high during dry seasons and low flows, regardless of sewage strength. Due

to this condition power consumption figures should be closely analyzed before drawing conclusions.

HP./m.g.d. merely indicates a rate of power and is tied in only with the rate of flow to the sewage plant, while KWH./pound of B.O.D. removed by aeration gives a better picture of how efficiently the plant operator is using the aeration equipment. This point is well illustrated by Figure 2. Curve A represents monthly average data ob-

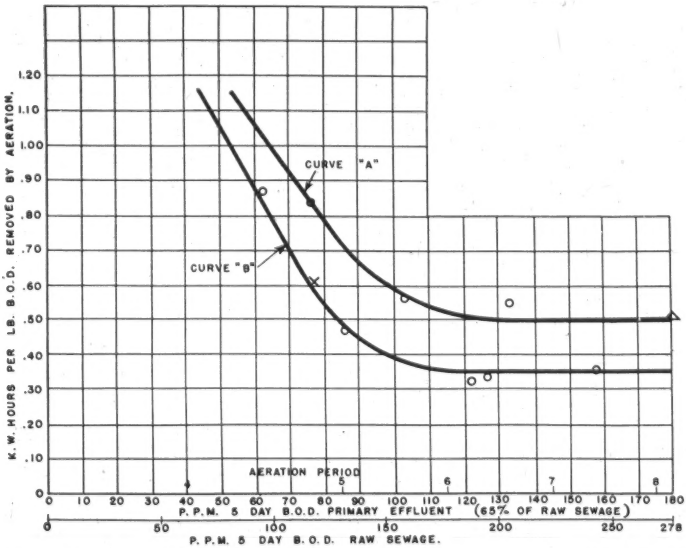

FIG. 2.—Average monthly data from several plants showing power consumption for plant operation.

tained from plants where no special effort was made to obtain economical operation. Curve B represents monthly average data obtained from plants under careful control to obtain maximum economical operation.

The total aeration power consumption per million gallons of sewage treated for the average mechanical aeration plant and diffused air plant is about the same. With mechanical aeration the comparatively longer detention period offsets the lower rate of power consumption.

During the past four years there has been a definite trend toward the design of mechanical aeration batteries with sufficient flexibility in equipment and tank arrangement to operate as close to the present flow as possible, in order to bring out the actual possible savings due to the lower rate of application of power in mechanical aeration.

In mechanical aeration plants greater flexibility in power economy can be effected than in compressed air plants, by means of time switch

control. Time switch control allows the operator to pro-rate the power usage to the actual organic load being handled. The smaller sized mechanical aeration tanks may permit further power economies seasonally. At times it may be possible to take one or more units out of service while in compressed air plants even though a tank can be taken out of service, generally smaller blowers are not available to permit savings in power at such times.

Power consumption for aeration alone and for all purposes was observed to vary to some extent at existing plants. This variation is believed to be caused by the following two major factors (1) the degree of operation supervision, and (2) to the fact that the average sewage flows were generally much less than the design plant capacities. As a consequence, either more mechanical equipment than is necessary or equipment selected for design capacity but at present oversized and using more power than is necessary, are in use for the existing flows. Due to these conditions, it is difficult to make a true comparison between the power consumption at existing mechanical aeration and diffused air plants.

Due to the lack of operating data and separate current meters it was impossible to secure, at many plants, data or a breakdown of the total current used for all purposes and to pro-rate the current used only by the aerators. The power data collected are set forth in Table I.

Construction Costs.—A study of 15 existing plants, ranging in capacity from .050 to 2.25 m.g.d., which may be used to give an indication, shows an average cost of construction of $148,000 per m.g. or $19.30 per capita. The lowest cost per m.g. was $80,000 and the highest $310,000. The lowest cost per capita was $8.00, the highest $35.50 at an institution, due to the use of higher per capita design flows.

TABLE I.—*Power Consumption Data*
Mechanical Surface Aeration Plants

Plant No.	Design Capacity M. G. D.	Average Flow M. G. D.	Total KWH. used Per M. G.	Total KWH. Aeration Per M. G.	Annual Operating Cost Per M. G.
1	.370	.121	822	740	
2	.500	.256	888		
3	.560	.412	824		$23.36
4	.600	.177	910		
5	.600	.420	873	765	
6		.675	863		19.30
7	.674	.200	1000		
8	1.180	.729	680	436	24.40
9	2.0		1050		
10	2.25	.988	355	318	
11		.800	1000		
TOTAL			9265		
AVERAGE			842		

Compressed Air Diffusion Plants

Plant No.	Design Capacity M. G. D.	Average Flow M. G. D.	Total KWH. used Per M. G.	Total KWH. Aeration Per M. G.	Annual Operating Cost Per M. G.
1	7.0	5.41	507	446	
2	.25	.175	800		
3	6.0	3.942	488	413	
4		2.75	1000		
5		3.90	845		
6	2.0	1.64	575		
7	6.0	3.00	1000		
8	1.0	.85	915		
TOTAL			6130		
AVERAGE			766		

The construction cost, excluding land and engineering fees, obtained for 15 existing mechanical plants and 9 compressed air plants are plotted on Figure 3. These plants are located in the midwest and

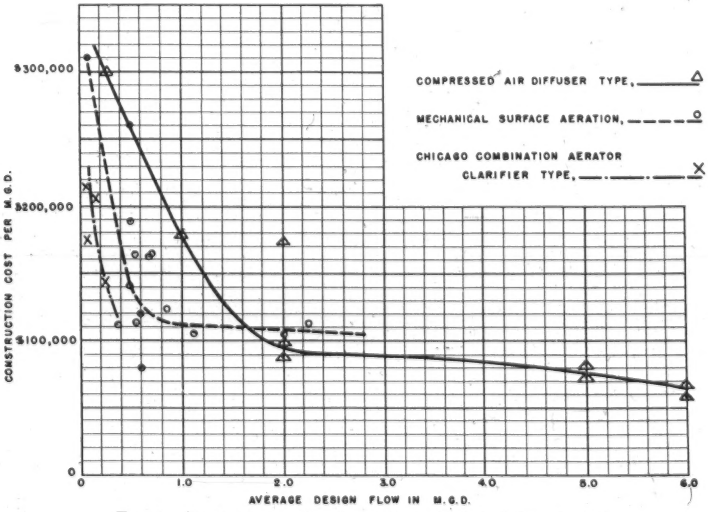

FIG. 3.—Construction costs of existing activated sludge plants.

east. Their operating structures are generally similar, but not in all details. The graph indicates that the dividing line on construction cost is approximately at a design flow of about 1.5 m.g.d. Due to the shorter aeration period being used by compressed air plants, resulting in savings in concrete and other materials, estimates indicate the cost

of construction of the two types of plants is about equal for a design flow of 1 to 1.5 m.g.d. at present prices. At the smaller plants the lower cost of mechanical aeration equipment offsets the larger amount of concrete that may be needed in comparison with compressed air plants.

Kessler reported in January, 1938, that there were 170 activated sludge plants in the United States. Eighty-eight of the 150 licensed by Activated Sludge, Inc., or over 50 per cent of the total number, are of the mechanical surface aeration type. The largest known operating mechanical aeration plant in the U. S. has a capacity of about 4.0 m.g.d. and is located at Elmhurst, Ill. The smallest known mechanical aeration plant operating at the present time has a capacity of 0.070 m.g.d. and is located at State Park, S. C.

Conclusions

Studies incorporated in the body of this paper indicate the following conclusions:

1. Activated sludge plants of the mechanical surface aeration type have made it possible for small towns to provide complete treatment at a low first cost and reasonable operation cost.
2. The decisive factor generally responsible for determining whether an activated sludge plant of the mechanical surface aeration or of the compressed air diffusion type should be used, appears to be first cost.
3. Power consumption and power guarantees should not be compared on the ability of the equipment alone, because performance is dependent upon efficient plant operation and proper design.
4. The successful operation of a large number of activated sludge plants has been due to a great extent to the mutual interest and cooperation between designing engineers, plant operators, and equipment manufacturers after the plants are placed in operation.

Acknowledgment

The writer wishes to acknowledge his indebtedness and gratitude for all data furnished by designing engineers, and plant operators, and for that secured from publications and by direct visits to treatment works. Special acknowledgment is due to Milton Spiegel, Phillip Morgan, and A. C. Durdin III, Sanitary Engineers, Chicago Pump Co., for their kind guidance and suggestions.

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THE USE OF HYDRATED LIME IN THE ACTIVATED SLUDGE PROCESS

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Introduction

Lime has been used in many activated sludge plants in an effort to control, or prevent, bulking of the sludge. Points of application have varied from primary settlers to final clarifiers. The treatment has been reported to be successful at some plants and of little or no value at others. The operators of those plants where lime has been found helpful are not in agreement as to the function of the lime. Some attribute its value to pH control, some to the killing of filamentous growths and some to the weighting down of the sludge floc. The writer has tried lime on several different occasions, with varying success, in two widely different plants. These experiences will be described, in conjunction with a review of the experiences of others, after which an attempt will be made to explain the action of the lime and to offer suggestions as to when, where and how it should be applied to give the best results.

A Review of the Literature

After nearly five years of successful operation, severe bulking accompanied by heavy growths of *sphaerotilus* were encountered at the Des Plaines Plant [1] of the Sanitary District of Chicago. Various chemicals, including chlorine, copper sulfate and sulfuric acid, were tried in varying quantities with little or no success. Finally lime was added to the outlet of one aeration tank (188 p.p.m. based on flow of sewage plus sludge for the day) and the influent sewage shut off. The tank contents were aerated for several days. The lime coagulated the floc, which regained its brown color and appearance after continued aeration. When sewage was again admitted to the tank the sludge soon returned to its slimy condition. "Later an equal amount of lime was added to each of the other tanks with some improvement the following week, followed by a recurrence of bad effluents. It was apparent that the difficulty could be controlled fairly well by the addition of large amounts of lime, and a dry-feed machine was installed for that purpose." The incoming sewage had a pH of 5.6 to 6.2 with an occasional minimum of 5.2. Later that month the source of the trouble was discovered to be carbohydrate wastes, which were diverted to the river. It is significant that the Des Plaines treatment consisted of lime plus aeration, not lime alone. Morgan and Beck [1] reported that protracted aeration alone would usually reduce bulking temporarily.

Donaldson [2] describes bulking troubles at Tenafly: "Bulking was always accompanied by an increased or profuse growth of *sphaerotilus*.

. . . At first indications of bulking, hydrated lime was used for a period of 6 to 12 hours, in a dosage sufficient to maintain a reaction of pH 8.6 to 8.8. The lime was applied at the inlets of the aeration tanks and the control tests were made at the outlets. Too little lime does no good and too much lime results in an impairment of clarification. . . . On some occasions lime was not applied early enough or in sufficient amounts to control the situation. Applications of lime at the inlet to the clarifiers, though more economical, did not give as good results as at the inlet of aeration tanks. The lime treatment must be repeated frequently as it is not a permanent remedy for bulking." He reports that the usual lime dosage was 428 to 512 p.p.m., but it is not clear just what flow those figures are based upon. He attributes the success of the treatment to the production of a pH that is inhibitory to *sphaerotilus*.

Riese,[3] after studying sludge bulking at the Griffith Park (Los Angeles) plant, states "On December 18, 1931, the plant was found in a seriously bulked condition. The pH was 8.5 and the volume of suspended matter after 30 minutes settlement was 98.85 per cent. A liter sample, taken directly from the aeration tank, was dosed with about 10 grains of lime (CaO). Settlement to 23 per cent was effected within a few minutes. Celite and sand were added with lime causing the sludge to settle more rapidly than with lime alone. . . . The addition of lime was effective in breaking up the long, compacted, interwoven filaments into clusters. This suggests that merely the weight of the particles of lime in the sample may have a mechanical breaking up effect. Too much lime produced a milky supernatant liquid. Addition of sand to a liter sample of bulked sludge and shaking for a few minutes also caused settlement of the sludge."

S. M. Bennett, Chief Operator of the Griffith Park plant, briefly summarized his experiences with lime in some unpublished remarks before the 1932 Spring Meeting of the California Sewage Works Association: Heavy lime applications were made to the return sludge as it entered the reaeration tanks; at first no change was noted, but as liming continued, clarification deteriorated and, finally, a very turbid effluent was produced. Then the lime dosage was reduced to 25 to 50 pounds per day, all of which was applied to the reaeration compartments at the time of peak flow. Within a few days the effluent became crystal clear, sludge bulking and the rising of sludge in graduates or clarifiers was completely eliminated, and the capacity of the plant was almost doubled. Since then the amount of lime used has varied some with the quality of the sludge and the character of the incoming sewage, but has averaged about 100 lbs. per million gallons of sewage.

Goudey,[4] in a demonstration of bulking and debulking of activated sludge before the 1932 fall meeting of the same organization, stated that "sludge can not be bulked by pure cultures of *sphaerotilus* and bacterial filaments nor is it possible for them to multiply with the speed that bulking occurs. Bacterial filaments multiply on fruit and vegetable pulp, but their presence in greater numbers than found in bulked sludge has been observed in dense heavy sludge. . . . Sludge-bulking

appears to be simply a physical suspension of activated sludge held up by inorganic or organic substances themselves too light to settle rapidly."

He induced bulking in liter samples of sludge by addition of fruit pulps, followed by aeration for one hour. Another liter sample was bulked by the addition of one teaspoonful of milk of magnesia. Some of the samples were debulked with lime, one with fine silica sand and one with powdered decomposed granite in an effort to prove that the debulking process was purely a physical sedimentation. He used heavy dosages of lime to speed up sedimentation, but stated that smaller lime applications would accomplish the same results in a longer period of time. In the discussion which followed he attributed the success obtained with the use of lime at the Griffith Park plant to the fact that, first, a heavy sludge was built up and that, then, daily additions of lime were made in sufficient amounts to just maintain that weight.

Further unpublished discussions of the subject before the California Sewage Works Association in 1932 and 1933 brought forth the following data on the use of lime in some other California activated sludge plants:

Escondido.—This plant affords 5 hours diffused air aeration and 3 hours final settling to 175,000 gallons per day. Air consumption is 1.4 cu. ft. per gallon. Bulking gives very little trouble, but on occasion the sludge blanket rises considerably in the final clarifier. At such times one or more sacks of hydrated lime are dumped into the outlet of the aeration tanks and there is generally some improvement the following day.

Golden Gate Park (*San Francisco*).—This plant was new at that time and operation was not yet systemized. Lime was frequently used in small amounts in an attempt to control bulking. It was most commonly applied at either the mid-point of the aeration tanks or at the inlet of the final clarifiers. At times a milk of lime suspension had been applied uniformly over the surface of the final clarifiers. No conclusions had been drawn as to the best point of application or even as to whether or not the lime applications were beneficial.

Yosemite Valley.—Although the sewage reaching this plant had a pH of 6.8 to 6.6 the pH of the aerators frequently dropped to 6.4. Operator R. C. White stated that he had applied lime to the inlet of the aerators in sufficient amounts to bring their reactions near the neutral point on several occasions. No particular benefits from such treatment had been observed. (In 1935, White [5] reported using lime in quantity and manner described by Donaldson,[2] with no benefit with regard to bulking. He states that sludge bulking does not appear to upset the nitrification process, but that the addition of large quantities of lime seriously inhibited nitrification.)

Pasadena.—Some bulking difficulties were encountered at this plant in 1933 following the partial removal of some transverse baffles in the ridge and furrow aeration tanks. Hydrated lime was tried in amounts up to 500 pounds per million gallons. It was applied at various points

from the inlet of the aeration tanks to the inlets of the final clarifiers. The treatment was considered costly and of no benefit in controlling bulking. Later the baffles were replaced and bulking troubles were eliminated.

Los Angeles County Sanitation Districts.—This is a large plant treating a strong industrial sewage. In the fall of 1932 severe bulking was encountered. Lime was tried in one unit. It was applied at varying rates by means of a dry feed machine. Liming was continuous throughout the day and night. The point of application was varied. A total of 15 tons of lime were used during the trial. The conclusion was drawn that lime was of some benefit during the time of application, but that it had no lasting effect. Therefore its use was too expensive to constitute a satisfactory means of controlling bulking.

Mauzey [6] reports that at Phoenix the application of lime to the sludge reaeration chamber, or to the aeration tank influent, was quite successful in controlling bulking caused by peach and tomato cannery wastes, but that the same treatment was of no avail when bulking was due to phenolic wastes from a gas plant.

Smith [7] reports that during the 1934 summer drought the Lima sewage was unusually strong and high in temperature; bulking of the sludge caused considerable trouble. Various remedies, including increased air applications, various percentages of return sludge, ferric chloride applications and lime applications, were tried. All of these remedies failed except heavy doses of lime.

Rhodes [8] reports some success in controlling bulking at Hagerstown by applying lime to the waste sludge entering the primary tanks; however, such treatment "raises the pH of the sewage and results in a turbid effluent."

Anderson [9] reports that at Rockville Centre the sewage has a pH of 6.7 while the pH of the aerators is 6.9. "To determine the effect of a different pH (on bulking) lime was fed to produce various pH readings up to 8.2 for a period of three months; this procedure did not show any beneficial results." Later he found that bulking was primarily due to a lack of dissolved oxygen. Since supplying that deficiency his bulking trouble has been practically eliminated. However he states that "should sludge continue to run over 20 per cent by volume in 10 minutes for as long as 24 hours, and should the sludge not be properly removed in the final tanks, indicating a real bulking sludge, dry lime is fed directly to the mixed liquor to the extent of 150 p.p.m. . . . After liming the effluent will be somewhat inferior for about four hours, but shortly afterwards will show very good purification."

Morgan, Durdin and Spiegel [14] report that with the advent of hot weather severe bulking was encountered at Flora, Illinois. "Continuous tests indicated the presence of dissolved oxygen in the aeration liquor at all times. Microscopic observations of the sludge revealed heavy filamentous growths. The only protozoa visible were a few *vorticella*. . . . Ropes of this filamentous material formed in the final tank, growing to lengths of three feet. . . . The addition of lime in solution

to the primary effluent was employed for several days. A pH over 8.0 was maintained in the aeration mix by the lime. The pH of the aeration mix before the lime was added varied between 7 and 7.5. Liming the influent to the aerators produced a marked improvement in the settling rate of the sludge. However there was no improvement in the quality of the sludge. As soon as liming ceased the sludge bulked again to its former volume."

Salinas Experiences

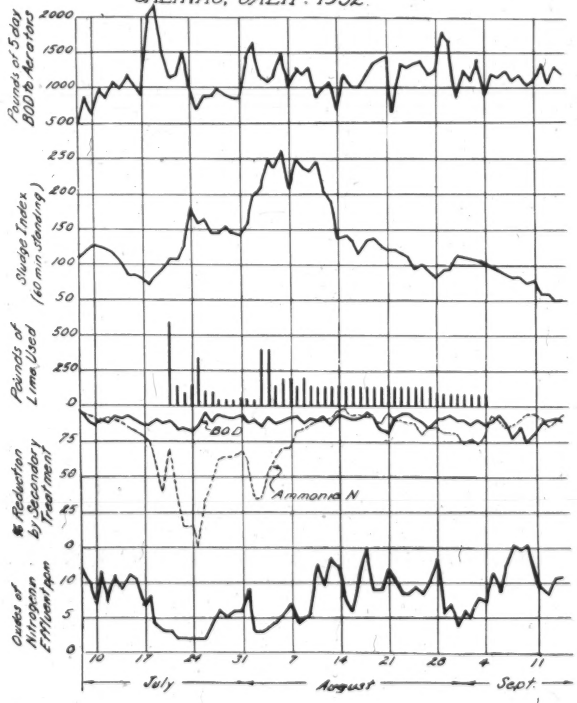
The writer operated the Salinas, California, plant during 1930–33 inclusive. The design and first two years operation of the plant have been previously described;[10] it will suffice to state here that the plant utilized compressed air and that the design of the final clarifiers was such that a satisfactory effluent could not be produced when the sludge index was much in excess of 300. (Attention is called to the fact that all sludge index data for Salinas are based upon a 60 minute settling period rather than the 30 minute period recommended by Mohlman[11] and now considered standard. Therefore the Salinas indices are all lower than the standard indices would be for the same quality of sludge. The higher the index the greater will this difference be.) During the first three years of operation insufficient blower capacity made it impossible to treat the entire sewage flow continuously. Early trials of chlorine and lime applied separately and/or together to the raw sewage, settled sewage, return sludge and aerator effluent had been disappointing. However, it was decided to make a more extended trial of lime during the summer of 1932. Lime was applied in 25 to 50 lb. batches to the inlet of each sludge reaeration tank at 1 or 2 hour intervals daily during the hours of peak flow. Figure 1 shows the amounts of lime used together with plant loadings and results preceding, during and immediately following the period through which lime was used. During the ten weeks covered by Fig. 1 an average of 330,000 gallons of settled sewage, or 1140 lb. of 5 day B.O.D., entered the aerators daily. Air consumption averaged 1190 cu. ft. per pound of B.O.D. Due to the use of "tapered aeration" there was usually some dissolved oxygen at all points of the aeration and reaeration tanks but it seldom, if ever, exceeded 1 p.p.m. at any point. The aeration period averaged 10.5 hours. After using variable amounts of lime for 46 consecutive days we concluded that although the continued use of 150 lb. per day might increase the plant capacity slightly, such increase was not sufficient to justify the cost of lime treatment.

Lime was not used regularly during September, October and November, 1932, but it was resorted to when severe bulking was imminent or present. The usual application consisted of 150 to 200 lb. per day applied as before. Application for one day did little or no good, but when used for from 3 to 7 consecutive days, lime always appeared to improve operation.

The activated sludge process was discontinued from December, 1932, to April, 1933, because of ample dilution for settled sewage. During

that time an additional blower was installed. The increased air supply made it possible to treat the entire sewage flow and still maintain adequate dissolved oxygen. However, some bulking was again encountered. Increasing the air from 4.4 to 5.2 cu. ft. per gal. was of no avail. Intermittent liming of the reaeration tanks, as used during the fall of 1932, was of little benefit. It was thought that continuous liming from 9 a.m. to 5 p.m. daily might prove more advantageous. To lime all of

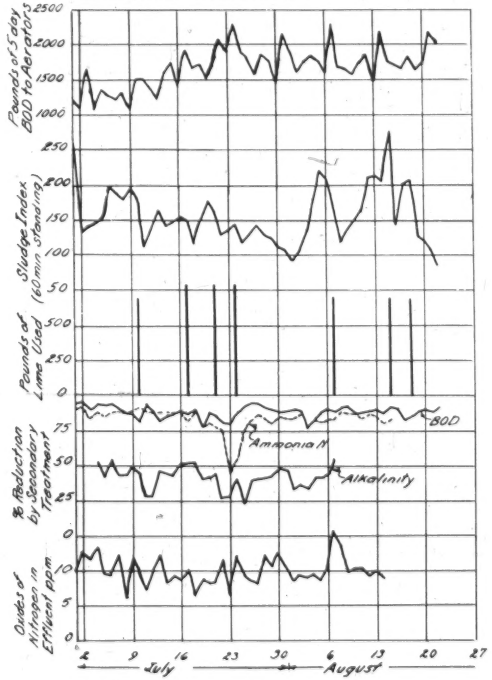
FIGURE 1
SALINAS, CALIF. 1932.



the return sludge would have required two points of application, one at each sludge reaeration tank, but by applying all lime to the settled sewage only one point of application was required. Therefore the later point of application was used. It was found necessary to make three applications of 800 lb. per day, over a six-day period, to overcome severe bulking. However, with a normal sludge the use of 200 lb. each day, applied continuously between 9 a.m. and 5 p.m., was found to be adequate. Later, we learned that by applying 600 to 800 lb. of lime at the rate of 100 lb. per hour for one day it was not necessary to use lime

every day. As a rule we used lime each Monday, that being the day of peak load on the plant. At times it was necessary to make two applications a week and at other times it was possible to skip a week. Figure 2 shows the plant operation during July and part of August, 1933. During that period an average of 550,000 gallons of settled sewage, or 1680 lb. of 5 day B.O.D., entered the aerators daily. Air consumption averaged 1450 cu. ft. per pound of B.O.D. Dissolved oxygen was

FIGURE 2
SALINAS, CALIF. 1933

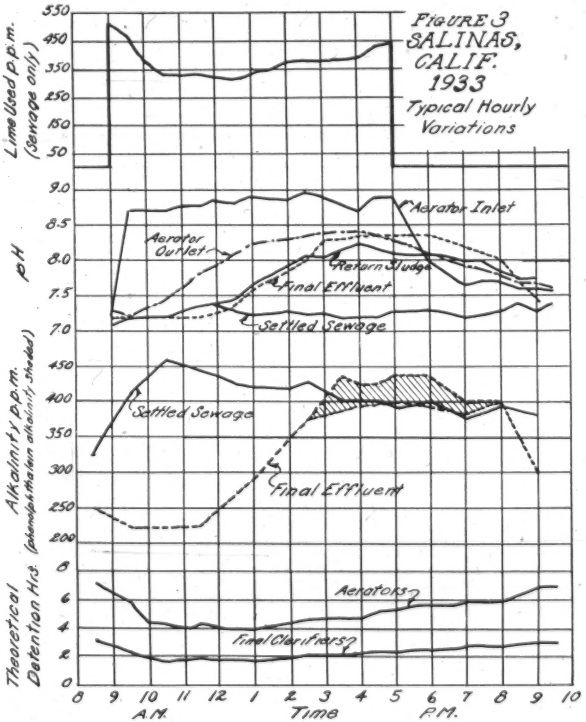


somewhat higher than during the period covered by Fig. 1, but the aeration period was only 7.8 hours instead of 10.5. Sludge reaeration, however, was approximately twice as long as it was during the earlier period.

Figure 3 shows the results of alkalinity and pH determinations through the plant on a typical day of liming, together with the theoretical retention periods and the amount of lime used. It is significant that although the pH at the inlet of the aerators was brought up to 8.7 or higher immediately, the pH at their outlets never exceeded 8.4 (on

some days it never exceeded 8.0). Although the theoretical aeration period was about 5 hours it required 6 hours for the pH at the outlet of the aerators to reach a maximum. The pH at the inlet of the aerators was above 8.7 for 8 hours, but the pH at their outlets remained above 8.0 for only 6 hours.

The use of these large amounts of lime appeared to have a slight "brightening" or clarifying effect on the final effluent as judged by its



appearance during the middle of the day on which lime was applied and on the day following its use. But during the time that the final effluent had a pH much above 8.0, *i.e.* while it contained normal carbonate alkalinity, it appeared cloudy or turbid. While it was evident that large doses of lime improved the settling characteristics of the sludge (see Fig. 2) their effect, if any, on oxygen demand reduction and on nitrification was not at all clear. Therefore, some rather crude laboratory studies were undertaken in the hopes of determining the effects of lime on B.O.D. removals and nitrification. It was also hoped to learn whether or not the increased turbidity of the effluent that obtained

whenever its pH was above 8.0 resulted in a corresponding increase in B.O.D.

Settled sewage and return sludge (before reaeration) were combined in the proportions of 2.125 parts of sewage to 1 part of sludge by volume. These mixtures were divided into four 1500 ml. portions, two of which were limed. Limed and unlimed portions were settled and their supernatants analyzed immediately. The other two portions were

TABLE I.—*Analyses of Sewages Used in Laboratory Tests with Lime*

	Test A	Test B
Suspended solids, p.p.m.	157	144
5 day B.O.D., p.p.m.	384	374
Ammonia nitrogen, p.p.m.	39	64
Total alkalinity, p.p.m.	420	430
pH	7.6	7.3

TABLE II.—*Analyses of Sludges Used in Laboratory Tests with Lime*

	Test A	Test B
Residue on evaporation, p.p.m.	3987	4238
Loss on ignition of residue, per cent	71.1	77.7
Total alkalinity of supernatant, p.p.m.	345	255
pH of supernatant	7.3	7.2

TABLE III.—*Analyses of Supernatants from Sewage-Sludge Mixtures Used in Laboratory Tests with Lime*

	Test A, 238 p.p.m. Lime				Test B, 136 p.p.m. Lime			
	No Aeration		5 hrs. Aeration		No Aeration		6 hrs. Aeration	
	Limed	No Lime	Limed	No Lime	Limed	No Lime	Limed	No Lime
5 day B.O.D., p.p.m.	221	221	128	110	204	204	103	105
Ammonia nitrogen, p.p.m.	32	34	18	18	52	52	8	8
Nitrogen as nitrites and nitrates, p.p.m.	—	—	9.5	9.5	—	—	7.0	6.0
Total alkalinity, p.p.m.	455	375	315	280	455	385	385	240
Phenolphthalein alkalinity, p.p.m.	105	0	10	0	65	0	15	0
pH	9.0	7.4	8.0	7.7	8.8	7.4	8.3	7.8
Sludge index	89	234	141	387	123	156	503	652

aerated for several hours, then settled and the supernatants analyzed. Two such series of tests were made. Table I gives analyses of the sewage used; Table II gives analyses of the sludge used and Table III gives analyses after combination, both with and without aeration. Aeration was accomplished by passing air through a ⅛-inch bore glass tube to the bottom of 2-liter bottles three-fourths full of the mixtures. This inefficient method of aeration, combined with the strength of the sewage and the lack of sludge reaeration, may explain the low B.O.D. reductions obtained and the bulking that occurred during aeration.

The sludge effected appreciable B.O.D. reduction without aeration. This amounted to 42.4 per cent in test A and 45.4 per cent in test B; dilution alone could account for only 32 per cent if the sludge supernatant had no B.O.D. of its own. The lime changed the color of the sludge from a dark brown to a more golden color. The large amount of lime used in test A clotted the sludge into stringy masses, but no clotting occurred in test B. Clotting decreased with aeration. The supernatant liquor in all limed samples was considerably more cloudy than in the corresponding unlimed samples. This difference was greater before aeration. Judging from the results of these tests, the turbidity did not increase the B.O.D. of the supernatant. These tests showed no change in B.O.D. removal, ammonia reduction or nitrification as a result of lime applications.

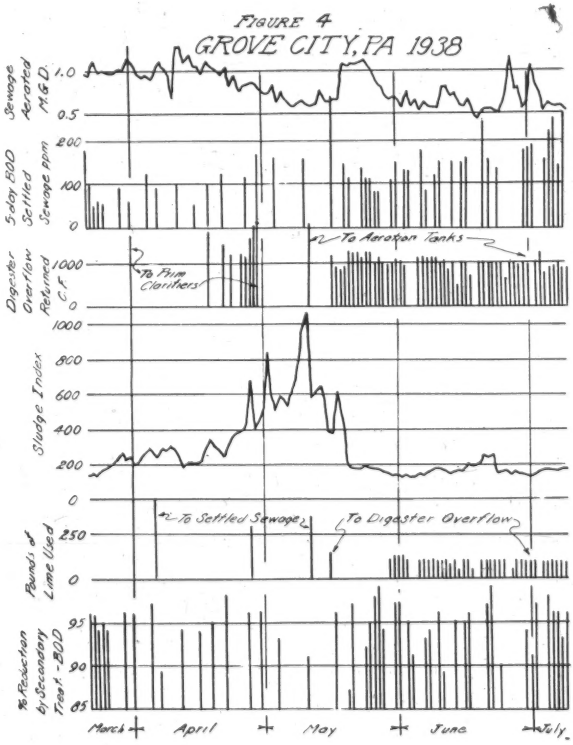
Grove City Experiences

The Grove City, Pennsylvania, plant originally comprised separate sludge digestion, to which activated sludge treatment with mechanical aeration has recently been added. The writer has been in charge of the plant since the activated sludge process was started in January, 1938, but devotes only part of his time to that plant, so uninterrupted laboratory data are not available. The Grove City sewers are subject to considerable ground water infiltration and some roof drainage. The sewage flow varies from 0.5 to perhaps 2.5 M.G.D. Whenever the flow exceeds 0.8 M.G.D. a portion of it spills over a bypass weir following the primary clarifiers and so does not receive final treatment. The maximum rate of flow through the aeration tanks is about 1.5 M.G.D., but the hydraulics of the plant are such that when such a flow obtains through the aerators approximately another million gallons per day is spilling over the bypass weir. There are a total of six American Well Works mechanical aerators. The flow to the aeration tanks is so divided that each half of it passes through three aerators operated in series.

When the activated sludge process was first started the settled sewage was very dilute and high in dissolved oxygen. A normal sludge was soon built up and excellent results were obtained. The sludge index varied between 100 and 200 and microscopic examinations revealed numerous ciliate protozoa, principally *vorticella* and *euplotes,* as well as the smaller flagellata. Filamentous growths were never observed until March 2nd. Since then they have always been present in greater or lesser numbers, but there has been no correlation between the number of filaments present and the sludge index. (As regards correlation between filamentous growths and sludge index the Grove City sludge is the direct opposite of that at Salinas [10] where "*sphaerotilus* was always present in a bulked sludge. Usually it was the predominating organism observed in a badly bulked sludge. It was never found in a good sludge.")

As the load on the aeration tanks gradually increased, due to decreased infiltration during March, the sludge index steadily increased.

Even with a sludge index close to 300, however, there was no sludge blanket in the final clarifiers and a very satisfactory effluent was obtained. (Figure 4 shows data on the operation of the Grove City plant during the spring and early summer.) Because of the continued rise in the sludge index we decided to try lime. On April 5th we added 450 lb. of hydrated lime to the settled sewage entering the aerators. It was applied at a uniform rate between 10 a.m. and 3 p.m. This proved to



be too heavy an application; the maximum pH produced at the outlet of the aeration tanks was 9.4 and that in the final effluent was 9.2. Microscopical observations indicated that this dosage greatly decreased the number of all organisms in the sludge and that the protozoa that remained were very sluggish. About a week was required for the return of normal activity and protozoal numbers. This application of lime resulted in only a slight and very temporary reduction in the sludge index. (See Fig. 4.)

By the latter part of April the digester overflow had become a thin sludge containing about 2 per cent solids. The addition of this liquor to the primary clarifiers turned the contents septic and caused much gas-buoyed sludge to rise to the surface. The septic sewage entering the aeration tanks caused rapid bulking, so that lime was again resorted to on April 27th. It was applied to the sewage entering the aerators at a fairly uniform rate between 10 a.m. and 3 p.m., but that rate was considerably less than was used in the earlier tests. Figure 5

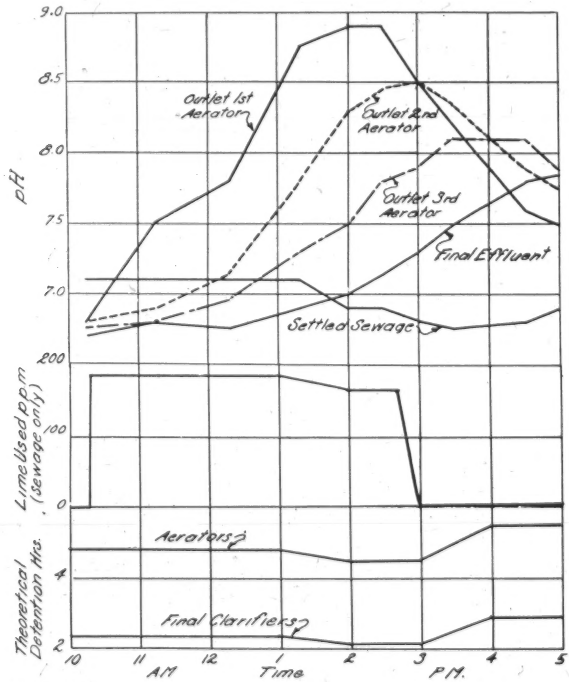


FIGURE 5

shows the hourly variations in pH and lime dosage for April 27th. The treatment reduced the sludge index from 674 to 393 and appeared to be of somewhat more lasting benefit than the previous trial, in spite of the continued pollution of the plant with digester overflow. Microscopical examinations showed that this lime application did not affect the numbers or activity of either the protozoa or the filamentous growths.

While the lime treatment was considered successful the condition of the primary settlers was so unsatisfactory that the digester overflow

was temporarily diverted to a small, overloaded sludge lagoon while piping changes were made to permit its discharge directly into the aeration tanks. Despite this relief, and all our efforts to the contrary, the primary tanks remained in a semi-septic condition until the heavy rains late in May brought down sufficient dissolved oxygen to remedy the situation. In the meantime the sludge index had increased to over 1000 by May 11th so we again resorted to liming the settled sewage. Despite the large volume of poor quality digester overflow that entered the aerators directly on that same day the results of the lime application were again quite gratifying. (See Fig. 4.)

However, since it was the digester overflow that caused our difficulties it was thought to be more logical to apply the "remedy" to the "culprit." All digester overflow liquor has to be pumped at Grove City no matter whether it is discharged to the primary clarifiers, aerators or lagoon. It is rather convenient to apply lime directly to this liquor during the pumping process. Since the later part of May, 1938, we have pumped all digester overflow direct to the aerators after adding from 1150 to 2000 p.p.m. of hydrated lime. Before liming, the pH of the digester liquor ranged from 6.5 to 7.1; after liming it ranges from 7.5 to 8.8. This treatment requires at least twice as much lime as would the application of occasional heavy doses of lime to the settled sewage, but it produces more uniform results and, in our particular case, is considerably more convenient.

Discussion

It will be readily observed from the foregoing discussion that the lime has been applied ahead of, or during the early stages of, aeration at all plants in which its use was found to be beneficial. In at least one case [2] where lime ahead of aeration gave good results, its use after aeration was of little value. This would indicate that the decrease in sludge bulking was due to *lime plus aeration and not to lime alone.* This fact, alone, casts considerable doubt on the validity of some, if not all, of the theories offered to explain the action of the lime. However each of those theories will be briefly discussed.

The Weight Theory.—It has been claimed by some [3, 4] that merely the weight of the added lime particles improved the settling quality of the sludge. The A. P. H. A. Committee on Sewage Disposal [12] reports that "various investigators have, from time to time, suggested the addition of finely divided inert mineral matter to the return sludge to aid in the final settling, based on the common observation that activated sludges with a higher proportion of mineral or fixed matter settle more rapidly than those higher in volatile material. Clay, silt, carbon, lime or limestone have been suggested." More recently Ely [13] has graphically described his success in controlling bulking at Ontario by shoveling fine clay soil into the aerators. The writer had a startling demonstration of this phenomenon at Salinas when a break in the sewer permitted a large volume of irrigation water and silt to enter

the plant. Such remedies may be satisfactory for bulking due to "shots" of some disturbing element over short periods of time and at infrequent intervals, but as a steady "diet" they would have many disadvantages.

Actually lime is not an inert material. As soon as it enters the sewage, or sludge, it combines with the carbon dioxide to form calcium bicarbonate, a soluble compound which passes out with the effluent. If sufficient lime is used to bring the pH up to about 8 or higher, calcium carbonate will be produced. Since the carbonate is only slightly soluble some of it may precipitate and actually, weight the sludge down. That explanation may be valid for laboratory experiments in which large amounts of lime are used such as those performed by Reese [8] and Goudey.[4] It cannot explain the benefits of daily applications of small amounts of lime that do not materially increase the pH of the final effluent, such as were used at Griffith Park, Salinas and Grove City. Even when relatively large amounts of lime are used less frequently, the pH of the sewage is not high enough to permit the deposition of carbonate for more than a few hours, while the benefits of the treatment are usually noticeable for several days.

The Control of Filamentous Growths.—In 1932 the writer [10] stated that "the primary cause of sludge bulking is insufficient biological oxidation to keep pace with adsorption." Since then a great deal of research work has been done on the mechanism of clarification, or adsorption, but nothing has been brought forth to diminish the importance of biological oxidation. At the same time the writer stated that the first appearance of *sphaerotilus* in the sludge is an indication of a condition, but that its presence in large numbers may cause further bulking by physical separation of the sludge floc. Thus a bulked sludge might contain few, many or intermediate numbers of filamentous growths and still its bulking be primarily due to a lag of biological oxidation behind clarification, *i.e.* insufficient reactivation. However, many eminent authorities [12] recognize two distinct types of bulking: "*A.* Sludge flocculated, high index, little or no growth of *sphaerotilus,* and *B.* Sludge slimy and deflocculated, no definite separation between solids and liquid, filamentous organisms present in excessive amounts." Concerning the relationship between *sphaerotilus* and bulking, Smit [15] states that "evident as this relation may seem the crucial experiment, *viz.,* causing the sludge disease by adding the organism to healthy sludge, has not yet succeeded."

In 1928 a bacteriological study of the filamentous growths isolated from bulked sludge at the Des Plaines plant was made by Ruchhoft and Watkins [16] who reported as follows: "Optimum growth is obtained in broth at 20 to 25° C. with a pH between 7.0 and 8.0. No growth ever appeared with a pH less than 6.0 or greater than 8.8. Growth is not only suppressed, but the organism is killed when subjected to a pH less than 6.3. . . . Laboratory experiments showed that prolonged aeration of the sludge up to 96 to 120 hours helped the settling quality of the sludge and greatly reduced the number of filaments but did not

eliminate them. . . . Experiments showed that with lime doses of 500 p.p.m. or over, most of the filamentous organisms are dissolved or disintegrated in a short time. Doses of from 100 to 500 p.p.m. (of lime) are also decidedly helpful in reducing filaments, but doses under 100 p.p.m. have little or no effect on the sludge." In 1934 Smit [15] again investigated the organisms. His findings agreed with those of Ruchhoft and Watkins as regards temperature and pH for optimum growth.

From the foregoing summary of the literature it is evident that lime is seldom, if ever, applied in sufficient quantities to raise the pH of the sludge to 8.8 for more than a very few hours. Even at plants where relatively large amounts of lime were used the successful treatment was lime followed by aeration and not the reverse. Therefore, it appears logical to believe that the benefits of lime were due to some other cause that the production of a pH inhibitory to the filamentous organisms. At Salinas, where bulking was always accompanied by profuse growths of *sphaerotilus*, we were able to prevent bulking by the use of about 40 to 50 p.p.m. of lime, although the pH of the effluent ranged from 7.1 to 7.4.

Since sewage usually has a pH near or below the optimum for the filamentous organisms, the use of acid would appear more logical than the use of lime for suppressing their growth. Such treatment proved partially successful at Leipzig. However, other factors than filamentous growths must be considered. For example, at Des Plaines [1] the pH of the incoming sewage was already too low for optimum biological oxidation; under such conditions, at least, the use of acid apparently suppresses oxidation more than it suppresses filamentous growths.

Adjustment of pH.—The necessity of biological oxidation, or sludge reactivation, is an accepted fact. It is also well known that all biological processes are sensitive to the hydrogen-ion concentration. Therefore, it would be of interest to know the optimum pH for the organisms responsible for such oxidation.

Butterfield [17] has isolated and studied a zooglea forming bacterium from activated sludge which when introduced into sterile sewage produced a floc simulating activated sludge. He found growth of that organism over a pH range of 5.6 to 8.5 with optimum development at 7.0 to 7.4. However "the alkalinity of the sewage was increased by the growth of that organism until a pH of 8.6 to 8.8 was reached." In that respect the organism differed from normal activated sludge, which invariably reduces the alkalinity of the sewage being treated, whether or not there is any change in its pH.

Levine and Soppeland [18] studied various bacteria isolated from activated sludge and from creamery wastes. Aeration hastened the action of all bacteria studied. The optimum reaction was found to be at pH 7.0 to 7.5, but initial values of 6.4 and 8.4 were not inhibitory under aerobic conditions. Proteolysis was retarded and frequently stopped if the reaction reached 5.5 to 5.0. In general the reactions of the alkaline inoculations became more acid and those of the acid series

more alkaline, the changes tending toward the optimum for the various cultures. The development of most of these cultures was accompanied by an increase in titratable acidity regardless of pH changes.

Wooldridge and Standfast [19] found that the optimum reaction for the oxidation of sewage was pH 7.3 with marked reduction of rate at pH 5.0 and 10.0 and complete inhibition at pH 4.0. At Grove City a pH of 9.2 to 9.4 diminished microscopical life and appeared to retard oxidation.

Table IV gives average pH values for various activated sludge plants as obtainable from literature available to the writer.

TABLE IV.—*Average pH of Aerator Influents and Effluents at Various Activated Sludge Plants*

Plant	Influent	Effluent
Durham, North Carolina	7.1	7.0
Golden Gate Park, San Francisco, Calif.	7.3	7.3
Grand Canyon, Arizona	7.5	7.2
Griffith Park, Los Angeles, California	6.6	7.0
Grove City, Pennsylvania	6.9	7.0
Hagerstown, Maryland	7.2	7.3
Harlem Valley State Hospital, New York	7.2	7.1
Mason City, Iowa (Exp. plant meat packing)	6.7	7.7
Menomonee Falls, Wisconsin	7.2	7.2
New Jersey State Hospital	7.4	7.3
Phoenix, Arizona	7.3	7.4
Pomona, California	7.5	6.9
Rockville Centre, New York	6.7	6.9
Salinas, California	7.4	7.3
Topeka, Kansas	7.5	7.5
Waverly, Iowa	7.2	7.3
Yosemite, California	6.7	6.4

All of the above data point to the fact that, normally, biological oxidation will progress satisfactorily at a pH range of 7.0 to 7.5, but that considerably higher or lower reactions are not necessarily deleterious. Therefore, it is necessary to conclude that the beneficial effect of lime applications is due to something other than the adjustment of the pH to the optimum for biological activity.

Other Factors Influencing Biological Activity.—There are numerous factors other than hydrogen-ion concentration which influence biological activity. One is temperature, which is not susceptible to control by the operator. Another is food supply—organic matter and oxygen in the case at hand. Organic matter is always available in the normally operating plant. Dissolved oxygen determinations on mixed liquor give a measure of the *excess* of oxygen supply over oxygen demand. It is absolutely essential that the supply be at least equal to the demand, but there is nothing to indicate that an appreciable excess is beneficial; Heukelekian [22] states that a minimum of 0.5 to 1.0 p.p.m. of dissolved oxygen maintained at all times and in all sections of the aeration tanks is the most economical range. Still another influencing factor is the elimination of the end products of biological metabolism. Carbon dioxide is the principal end product of aerobic decomposition,

just as methane and carbon dioxide are the main products of decomposition under anaerobic conditions. In the writer's opinion the chief benefits gained from the use of lime in the activated sludge process may be ascribed to the reduction in carbon dioxide resulting from its use.

Carbon Dioxide Production and Its Elimination.—Since CO_2 results from either anaerobic or aerobic decomposition its production probably starts as soon as the sewage is produced. Ammonia is another decomposition product, the formation of which starts almost as soon as the materials enter the sewer. Ammonia and carbon dioxide combine with water to form ammonium bicarbonate which is, perhaps, the principal cause of the increase in the alkalinity of the raw sewage over that of the water supply from which it resulted (See Table V). There is a direct relationship between the pH, alkalinity and free carbon dioxide content of water. It may be expressed as follows:

$$\log CO_2 = \text{Constant} + \log \text{Alkalinity} - \text{pH}.$$

The constant varies with the temperature and the partial pressure of carbon dioxide in the atmosphere in contact with the liquor surface. For the purposes of approximation it may be taken as 6.3 for normal atmospheric conditions when the alkalinity is expressed as parts per million of $CaCO_3$. If we neglect the alkalinity of sewage due to weak organic acids the same relationship may be applied to sewage. If we assume a raw, or settled, sewage to have a pH of 7.0 and an alkalinity of 300 p.p.m., its computed free CO_2 content will be about 60 p.p.m.

In waterworks practice aeration is considered a ready means of reducing dissolved CO_2. Whipple [23] gives data to show that exposure of water to air in drops for 15 seconds reduced its carbonic acid content from an initial 50 p.p.m. to a final 2 p.p.m. Even granting that aeration as practiced in the activated sludge process is not as thorough as that reported by Whipple, one would expect, in view of its longer duration, substantially the same reduction in CO_2. The above equation illustrates that when the carbon dioxide is reduced either the alkalinity is reduced, the pH increased, or both. Table IV shows that there is about as much chance of the pH falling during aeration in the activated sludge process as there is of it increasing. If we assume a final effluent to have 2 p.p.m. CO_2 and a pH of 7.0 (as assumed above for a raw sewage) we find that the alkalinity remaining would be only 10 p.p.m., a reduction of 290 p.p.m. Table V shows that although there is a substantial reduction in alkalinity during the activated sludge process it is nowhere near as great as in our assumed case. The only logical explanation of this apparent discrepancy is that the CO_2 content of the sewage is not greatly reduced during the process because the rate of production of carbon dioxide by biological oxidation is almost as great as the rate of its removal by aeration.

Heukelekian [20] and Ingols [21] have measured the rate of carbon dioxide production, or rather elimination, during the activated sludge process. During a 3.3 to 5.5 hour aeration period, mixtures of 20 per cent

sludge and 80 per cent sewage gave up from 96 to 292 p.p.m. of CO_2. When the rate of CO_2 elimination is plotted against time, the normal curve obtained resembles that of the rate of oxygen utilization by activated sludge-sewage mixtures in that the maximum CO_2 elimination occurs during the initial aeration period. The duration of that maximum rate varied from 20 minutes to 7 hours. After that period the rate decreased to a lower, practically uniform, rate which continued, with only slight diminution, for as long as 5 days. Generally speaking, the higher the B.O.D. of the sewage the greater the amount of CO_2 produced, the higher the initial rate of its elimination and the longer the duration of that high rate. However two sewages of the same B.O.D. may have entirely different rates of CO_2 elimination. The rate was

TABLE V.—*Reduction in Alkalinity by the Activated Sludge Process*
(Basic Data from Reinke [24, 25])

Plant	Total N in Raw Sew.	Oxides of N Final Effl.	Alkalinity			Reduction in Alkalinity		
			Water Supply	Raw Sewage	Final Effl.	Total by Act. Sludge	Due to Nitrification	Due to CO_2 Removal
Escondido	37	4.5	152	317	205	112	16.4	95.8
Lodi	29	1.3	140	267	242	25	4.7	20.3
Pasadena	48	5.5	125	252	181	71	20.0	51.0
Pomona	45	7.5	120	304	149	155	27.2	127.8
Salinas (total flow)	50	1.4	220	420	376	44	5.1	38.9
Salinas (½ flow)	48	17.8	220	440	257	183	64.6	118.4
Santa Barbara	25.5	4.8	280	350	292	58	17.4	40.6

also found to vary for the same sewage when mixed with different sludges, thus indicating that the character and stage of oxidation of the sludge may be a factor. It was frequently found that the rate of CO_2 production from a mixture of sewage plus sludge was greater than would be anticipated from the corresponding rates for the sewages and sludges alone, and that the greater the proportion of sludge in the mixture the greater this increase in CO_2 production. This corresponds with some of the results obtained by various investigators when measuring the oxygen utilization of sewage-sludge mixtures, and, also, with the well known fact that increasing sludge concentrations increase the rate of purification during the first few hours more than they increase the overall purification.

While the maximum carbon dioxide concentration possible without retardation of biological activity is not known, it is an established fact that excessive amounts will produce deleterious effects. In view of the high CO_2 concentration usually present in raw sewage and the high rates of its production during the aeration process it seems logical to believe that, with certain sewages or sludges, the CO_2 content of the mixed liquor may be sufficiently high to slow up biological action. Although, as previously stated, there is nothing gained by carrying a

high dissolved oxygen content in the aerators some operators follow that practice. Perhaps the benefits derived from such methods are due more to the speeding up of carbon dioxide removal as a result of increased aeration than to the higher dissolved oxygen itself. At any event the use of lime suggests itself as a logical means of assisting aeration in eliminating CO_2 from solution when ever its concentration may be a limiting factor in the rate of biological oxidation.

The Use of Lime for Carbon Dioxide Removal.—Since CO_2 production is greatest during the early stages of aeration it is logical to apply the lime either to the sewage or to the sludge just before the two are mixed together. Conversely, CO_2 production is low at the outlets of the aerators, and probably lower yet in the final clarifiers, so lime applications at those points would be of less value. Such was the case at Tenafly.[2] If aeration is not sufficient to maintain at least a trace of dissolved oxygen at all times and at all points of the aerators, then the lack of oxygen is probably the limiting factor rather than the excessive CO_2 and the use of lime could not help matters appreciably. Such was apparently the case at Rockville Centre.[9] Time is required for biological oxidation even under the best of conditions; after the initial high rate when sewage and sludge are first aerated, oxidation continues at a lower, more uniform, rate during which time the adsorbed matter in the sludge is gradually oxidized. While the reduction of CO_2 in the sludge liquor may speed up the rate of oxidation it cannot entirely eliminate the time element. If sufficient time is not allowed for sludge regeneration, or reactivation, oxidation will gradually lag behind adsorption until the sludge bulks, or loses its clarifying power, or both, despite the maintainance of dissolved oxygen and the elimination of carbon dioxide. Such was probably the case at Yosemite [5] and Pasadena, where bulking was apparently caused by short-circuiting.

When lime is added it first reacts with the CO_2 to form $Ca(HCO_3)_2$; if more than enough lime to react with all of the free carbon dioxide is added, some of the bicarbonates are converted to normal carbonates. This later reaction does not occur until the pH is about 8.0 or higher. When about 100 p.p.m. of lime, or more, is added to the sewage entering the aerators both of these reactions probably occur, but the normal carbonates are reconverted to bicarbonates by the CO_2 produced during oxidation, so that in effect all of the lime is used to reduce free CO_2 until such time as the pH at the outlet of the aerators reaches about 8. If liming is continued the normal carbonates will be carried through the aerators and into the final clarifiers. While it is true that $CaCO_3$ is quite insoluble and some of it may precipitate, thus weighting down the sludge, much of it when formed at a pH of 8.0 or slightly higher is colloidal in character and does not settle with the sludge but passes out with the effluent, increasing its turbidity and constituting a waste of chemical. Furthermore, once the pH reaches 8 the further addition of a relatively small amount of lime will greatly increase the pH and since it is already higher than the optimum for biological oxidation there is grave danger of the lime actually retarding oxidation rather

than assisting it. Such was the case at Grove City when a pH above 9 was obtained.

It is evident that the complete removal of CO_2 is not essential to the activated sludge process; in fact it might be harmful if continuous. Small daily additions of lime to the inlets of the aerators will reduce the CO_2 in the incoming sewage and assist its removal during the period of its maximum production, without materially altering the pH of the final effluent. Since strong sewages generally produce more carbon dioxide than weak sewages, such applications can be made only during the peak flow of strong sewage, and need not be continuous throughout the day.

When biological oxidation has lagged behind absorption for some time and the sludge is starting to deteriorate, even though dissolved oxygen is maintained, a relatively high lime dosage should be used and continued long enough to produce a pH of about 8 at the outlet of the aerators. A higher pH wastes lime and may be harmful. With very poor sludges a second or even a third application on following days may be required. Since lime is applied at the aerator inlets, while pH tests are made at their outlets, it is obvious that considerable experience is required to know just when to stop the lime application; pH determinations at frequent intervals and at various points throughout the aerators will be found helpful in this respect while "over shooting" the mark may not produce any permanent harmful effects, the writer greatly prefers to "under shoot."

Table VI is based on the daily analyses of composite samples at Salinas during the period covered by Fig. 2. The lime dosage, expressed as p.p.m. of $CaCO_3$ for the 24-hour flow, was added to the alkalinity of the settled sewage for that day and the hypothetical CO_2 content computed from the total alkalinity and the pH of the settled sewage given in the table. The alkalinity removed by nitrification was added to the alkalinity of the effluent and a second hypothetical CO_2 content computed from the total alkalinity and the pH of the effluent given in the table. The previously given approximate formula was used in those computations. The difference between the two computed CO_2 values was considered the net CO_2 removed by aeration alone, or aeration plus lime as the case might be. In computing the alkalinity removed by nitrification one part of nitrogen was considered equivalent to 5.73 parts of NH_4HCO_3 or to 3.63 parts of $CaCO_3$. While the data must be considered approximate only they do serve to illustrate the enormous amount of CO_2 removed by the lime, although the daily average pH and alkalinity of the effluent were not materially changed. Roughly five times as much CO_2 was removed on the days lime was used as on normal days and even on the days immediately following the use of lime the CO_2 removals were doubled. Since the hypothetical CO_2 content of the effluents did not vary nearly so much, it seems evident that a very real increase in biological oxidation resulted from the use of lime.

Effect of Lime on Nitrification.—Ammonia is converted to nitrites by *Nitrosomonas*, and nitrites are further oxidized to nitrates by *Nitrobacter*. Practically all oxidations in the activated sludge process are catalyzed by bacteria, but these two oxidations are peculiar in that they are brought about by specific organisms while mixed cultures of many types of organisms are responsible for most of the other oxidations. Although oxidation in general can progress satisfactorily over a wide pH range, as previously shown, it does not necessarily follow that nitrification can occur throughout that range. Theriault and McNamee [26] have found that while the nitrifying bacteria can become accustomed to, and flourish at, any pH value between 6.0 and 8.2, any strain of organisms accustomed to a particular hydrogen-ion concentration may require in excess of 10 to 21 days to acclimate themselves to such a relatively small change as one pH unit. The nitrite-forming

TABLE VI.—*Salinas Data—July, August, 1933*

	Days Lime Was Used	Days Following Use of Lime	Other Days
pH of settled sewage	7.20	7.14	7.24
pH of final effluent	7.44	7.27	7.20
Lime added as p.p.m. calcium carbonate	278	None	None
Alkalinity of settled sewage p.p.m.	415	399	414
Alkalinity of final effluent p.p.m.	297	276	260
Total alkalinity removed p.p.m.	396	123	154
Nitrogen as oxides in effluent p.p.m.	11.5	9.9	10.1
Alkalinity reduction due to nitrification p.p.m.	41.7	35.9	36.7
Alkalinity reduction due to CO_2 removal p.p.m.	354.3	87.1	171.3
Hypothetical CO_2 in settled sewage p.p.m.	871	562	479
Hypothetical CO_2 in final effluent p.p.m.	245	331	355
Net CO_2 removed p.p.m.	626	231	124

bacteria appear to be even more sensitive to pH changes than are the nitrate formers. In view of these facts one would expect a retardation of nitrification from the use of large amounts of lime at infrequent intervals while the daily use of small amounts of lime should have no material effect upon nitrification.

At Salinas, where the normal pH of the aerators was 7.3, we could observe no consistent change in nitrification as a result of the infrequent use of sufficient lime to bring the pH at their outlets up to 8.0 or slightly higher for a few hours at a time (See Fig. 2 and Table VI). In this connection it is noteworthy that the average pH of the effluent for the day, as obtained from composites of hourly samples, was only slightly above normal on the days lime was used. On the other hand, White [5] reports that at Yosemite, where the normal pH of the aerators is 6.4, the use of sufficient lime to bring the pH of the effluents up to 8.6 or 8.8 for 6 to 12 hours greatly diminished nitrification. Apparently the organisms could withstand the jump in pH from 7.3 to 8.0, but not the longer jump from 6.4 to 8.6.

However, there is another factor which must be considered; namely, the "sparing action of carbohydrates." Even though there are ample numbers of nitrifying bacteria present and the pH is maintained at the optimum for that particular strain of organisms, they do not function until most of the carbohydrates have been oxidized. Whether it is the carbohydrates themselves or the high concentrations of CO_2 resulting from their oxidation that retards nitrification is not definitely known; either one is a possibility although the blame is generally placed on the carbohydrates. At any event when biological oxidation lags behind clarification or adsorption long enough to induce bulking, the carbohydrates, along with other organic matter, build up in the sludge. Now if this lag has been induced by excessive carbon dioxide concentrations the use of lime will reduce the CO_2, hasten carbohydrate oxidation and thus bring about conditions suitable for nitrification. Such was unquestionably the case at Salinas. At Yosemite [5] where there was considerable short-circuiting in the aerators on high flows, and no sludge reaeration, it is quite possible that lack of time for oxidation rather than its retardation due to excessive carbon dioxide was the cause of bulking. If such were the case lime would be of little value in overcoming bulking and would certainly offer no incentive to nitrification.

Industrial Wastes.—Bulking difficulties are frequently attributed to industrial wastes. If the wastes are germicidal in character they will inhibit, or greatly retard, biological oxidation and cause it to lag behind adsorption; bulking will result. If the germicidal action is due to acidity the use of sufficient lime to correct that acidity should overcome the difficulty. Conversely, if the germicidal properties are the result of excessive alkalinity the addition of acid would help. Pre-treatment with carbon dioxide has also been found effective in such cases.[27] However, if the germicidal action is due to phenolic compounds, or other similar toxic substances, nothing but their exclusion from the aeration tanks will be effective. Such was the case at Phoenix. (In some cases, however, if the concentration of the toxic substance is quite uniform and not too great, it may be possible for the sludge organisms to become accustomed to it.)

Bulking has frequently been attributed to oils, grease or fats in the sewage. It has been the writer's experience [10] that unusual discharges of such substances always retard biological oxidation, but that such retardation may or may not be sufficient to induce bulking. He has found little or no benefit from the use of lime when applied simultaneously with the inflow of oil. Increasing the air supply during and immediately following the oil discharge was more effective; it seemed to aid in separating the oil from the sludge. However, a heavy application of lime on the day following the oil inflow was found to be effective in assisting biological oxidation to catch up.

Organic wastes such as milk wastes, fruit and vegetable cannery wastes, meat packing wastes, etc. increase the strength of the sewage and hence the amount of adsorption. Biological oxidation must be correspondingly increased to avoid bulking. If the wastes are mainly

carbohydrates, carbon dioxide production will probably be excessive and the use of lime should be of considerable value in removing it from the aerators. This was probably the case at Phoenix [8] where lime controlled bulking caused by peach and tomato wastes. Wastes high in nitrogenous matter are less likely to cause bulking. Eldridge, Mallman and Robinson [28] report that protein treatment increased the density and weight of the activated sludge solids. This may explain the dearth of recorded experiences concerning the use of lime in conjunction with the treatment of such wastes by the activated sludge process. Possibly enough ammonia will be formed to react with the carbon dioxide and hence prevent its concentration becoming excessive. If so, lime will be of no value in overcoming bulking caused by such wastes.

In some cases wastes may contain excessive amounts of carbon dioxide even though they have an alkaline reaction. The sewage plant's own "trade waste," digester overflow liquor, is one such waste. This liquor may have an alkalinity roughly ten times that of the sewage and it comes from an atmosphere containing perhaps 1000 times as much CO_2 as does the ordinary atmosphere; theoretically it might be expected to have a CO_2 concentration 10,000 times as great as that of the sewage. If the volume of digester liquor was 1 per cent of the total sewage flow it would double the carbon dioxide content of the sewage. Actually much of the CO_2 escapes from the liquor before it enters the aeration tanks, but, at least at plants where this liquor must be handled over a relatively short time, the increase in CO_2 may exert a retarding influence on oxidation processes. The application of lime to such wastes before they enter the aeration tanks has given good results at Grove City and is recommended for general use under similar conditions.

Conclusions

In the writer's opinion the foregoing data warrent the following conclusions relative to the use of lime to control sludge bulking in the activated sludge process.

(1) Experience at many plants indicates that lime is most effective when applied near the aeration tank inlets, and that the benefits to be derived from its use are due to lime plus aeration and not to lime alone.

(2) While it is possible to debulk sludge by the addition of heavier, inert, mineral matter to weight the sludge, the action of lime is not explained by that phenomenon. Most of the lime reacts with carbon dioxide to form soluble calcium bicarbonate, which passes out with the effluent. Even if sufficient lime is added to form the less soluble normal carbonate, only a portion of that salt settles out with the sludge; the balance remains in colloidal suspension and passes out with the effluent.

(3) It has been frequently reported that the use of excessive amounts of lime resulted in a turbid effluent. Some laboratory tests indicate that this turbidity does not increase the B.O.D. of the effluent.

The turbidity is believed to be due, primarily, to colloidal suspension of normal calcium carbonate.

(4) The bulking of activated sludge may be accompanied by anywhere from a very few to enormous numbers of filamentous organisms. Lime has frequently, but not always, been effective in reducing bulking whether or not such organisms are numerous in the sludge, thus casting some doubt on the claims that the benefits of lime are due to a killing off of filamentous growths.

(5) *Sphaerotilus,* the most common filamentous organism, may grow at any pH between 6.3 and 8.8; optimum development is at a pH between 7.0 and 8.0. The optimum pH for biological oxidation is 7.0 to 7.5 although there is little retardation at pH 6.4 or 8.0. Oxidation was retarded by a pH of 9.2 to 9.4. The similarity of these pH ranges leads to the belief that *sphaerotilus* growths cannot be destroyed by pH adjustment without impairing biological oxidation.

(6) The clarification of sewage by activated sludge is due in part to oxidation and in part to adsorption, both of which progress most rapidly during the initial period following the introduction of the sewage-sludge mixture into the aerators. Afterwards the adsorbed material is oxidized at a slower, more uniform, rate. Unless this biological oxidation keeps pace with adsorption the sludge will eventually lose its clarifying power. The primary cause of sludge bulking is a lag in biological oxidation behind adsorption. The control of bulking lies in either speeding up biological activity or providing more time for it to progress before re-introducing the sludge into the sewage.

(7) Among the possible causes of biological oxidation lagging behind adsorption are the following: (*a*) Inadequate oxygen supply, *i.e.,* no dissolved oxygen; however, oxidation progresses no faster in the presence of high D. O.'s than it does when 0.5 to 1.0 p.p.m. of dissolved oxygen are available. (*b*) Lack of sufficient time for biological oxidation, or sludge reactivation; this may be due to inadequate aeration tank capacity or to short-circuiting in the aerators. (*c*) The presence of germicidal wastes in the sewage, as for example phenolic wastes, acids or alkalies in excessive amounts. (*d*) Excessive accumulations of the end-products of biological metabolism. Carbon dioxide is the principal end-product of biological oxidation and excessive amounts of it are known to be toxic to bacterial activity although quantitative limits cannot be set.

(8) The use of lime will be of little or no benefit when bulking is due to inadequate oxygen supply or insufficient time for biological oxidation.

(9) Lime will not assist in treating germicidal wastes unless those wastes owe their germicidal properties to acids. In that event it is obvious that lime should be supplied whenever the pH is near or below 6, and sufficient lime should be used to raise the pH to about 7.

(10) Sewage contains relatively large amounts of carbon dioxide and much greater amounts are produced during the clarifying and oxidizing processes in the aerators. Although aeration is an efficient

means of removing carbon dioxide, the rate of its production during the activated sludge process is so great that the net reduction in CO_2 due to aeration may be slight in spite of the long aeration periods afforded.

(11) The use of lime offers a ready means of reducing carbon dioxide, and hence controlling bulking whenever the rate of biological oxidation is limited by the rate of elimination of CO_2. Since carbon dioxide production is normally greatest at the inlet end of the aeration tanks, that is the logical point to apply the lime. Either one of two general schemes may be followed in using lime for CO_2 removal, as follows: (*a*) Daily applications of 50 to 300 lb. of lime per million gallons per day of sewage. The application need not be continuous but may consist of from one to four "shots" during the hours of peak sewage strength and volume. (Strong sewages produce more CO_2 than do weak sewages.) This method will not overcome severe bulking very rapidly, but may prevent its occurrence. It does not materially alter the pH of the aerator contents, does not interfere with nitrification, aids in maintaining a sludge of uniform quality from day to day and requires no careful control. (*b*) When bulking is imminent, or already present, lime should be applied continuously to the inlets of the aerators at rates of 300 to 500 p.p.m. until such time as the pH at the oulet of the aerators approaches 8.0. The time required will probably be somewhat longer than the theoretical aeration period. Frequent pH determinations should be made to determine the exact time required. Care should be taken to avoid the use of too much lime because such practice is wasteful, and may be harmful. In severe cases of bulking it may be necessary to use two or three such treatments on alternate days, but as a rule one treatment will suffice for several days, or even weeks. Over a long period of time this method will require less lime than the first method, but will not maintain as uniform a sludge condition or effluent quality as will the first method.

(12) Nitrification is the result of the action of specific organisms which, while capable of functioning at any pH value between 6.0 and 8.2, are quite sensitive to changes in hydrogen-ion concentrations. Because of this sensitivity the infrequent use of heavy lime dosages may have a retarding effect upon nitrification, but such retardation will be only temporary. This effect will be more noticeable at plants where the normal pH of the aeration tanks is low than at plants where the pH is higher. On the other hand, the regular use of small amounts of lime will not retard nitrification, and may actually increase it.

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Industrial Wastes

THE PHENOLIC WASTE TREATMENT PLANT OF THE DOW CHEMICAL COMPANY

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The Dow Chemical Company, with its main plant located on the Tittabawassee River at Midland, Michigan, produces over 250 products. Situated on a 2,000-acre site, plant buildings now number over 300, in which are manufactured various industrial chemicals, intermediates, organic solvents, pharmaceuticals, aromatics, insecticides, dyes, and Dowmetal. Starting in 1897 to produce bromine and salt from a brine pumped out of a formation 1,200 ft. below the district, the industry has branched out, employing each new by-product to make a marketable product. The Company now has the largest and most modern phenol manufacturing plant in the world, and has become a major producer of the country's supply of aspirin, other salicylates, bromine, epsom salts, and magnesium metal.

The Tittabawassee River, source of the plant water, originates to the west and north of Midland. The flow of the river is regulated by hydroelectric plants upstream and average daily flows reach minimums as low as 150 cu. ft. per second during dry summer months. At such times the plant pumps practically the entire river flow. After receiving plant wastes, the river flows southeast to Saginaw where it is joined by other tributaries to become the Saginaw River. This river then flows north through Bay City to Saginaw Bay and Lake Huron. The city of Saginaw takes its raw water supply directly from the Saginaw River. The city of Bay City pumps water from Saginaw Bay at a point just a few miles west of the Saginaw River mouth, making it possible for easterly winds to move river water to the intake.

Pollution Control History

As the Company grew, correctional steps were taken to keep pace with the increasing volumes of waste water. The manufacture of phenol from benzol and the production of salicylates and a host of phenolic compounds, added wastes of a nature that could be objectionable in water in very minute amounts. The Company began early to pond its wastes. Waste brines were stored in huge ponds to be released during periods of high dilution. Process waters carrying precipitates and other suspended matter were ponded for settlement. Concentrated wastes containing soluble organic compounds were pumped to storage ponds before being carefully released during warm weather. By 1931, the Company had in operation over 600 acres of

diked ponds, three separate sewer systems, outlet structures and pumping equipment, all of which represented an investment of well over $1,000,000.

The present plant for treatment of phenolic wastes is the result of years of research. Starting in 1927, the Company has investigated practically all of the known methods of recovering or destroying phenolic compounds in dilute solutions. The mixed wastes, containing so many phenolic compounds, made recovery by extraction of useful products very expensive. Adsorption methods, while effective, were also thought to be too expensive. Biochemical methods showed considerable promise and an experimental plant employing the German "Tank Filter" was operated from September, 1935, to June, 1937. Trickling filters of various design and depth were also used in conjunction with the Emscher filters.

Comprehensive surveys of downstream river conditions over a period of years had clearly demonstrated that the critical period for phenolic pollution was during the months when river temperatures were less than 15° C. Strong phenolic waste was held in storage ponds during these months and only weak wastes reached the river. The problem, then, was to segregate all weak wastes from each phenolic product plant and to attempt to treat these diluted wastes. Further investigation of biochemical oxidation processes indicated that bacteria of natural soil origin were predominant in the biological units in which phenol was destroyed. These studies led to the experimental use of river water instead of sewage as a diluent for strong wastes and subsequently indicated that treatment of strong wastes diluted by weak wastes was possible.

Having established practical operating rates and acceptable effluents in experimental units, design of a full-scale plant was undertaken. The trickling filter was chosen as the biological unit because it was believed to be the simplest to design, construct, and operate. Past experience in sewage treatment has shown the trickling filter to be rugged in operation and resistant to variable demands or toxic substances. Extensive studies of filter media indicated that blast-furnace slag would be the best material for expected conditions from the standpoints of weathering, surface roughness, and chemical stability.

General Design Features

The actual design of the plant was begun in February, 1937. The general design features were based on the conclusions drawn from the data collected during the operation of the experimental plant. It was fully appreciated that this plant would serve as a large-scale experimental plant, and so the functioning elements were made as flexible in their operation as possible. Those parts of the plant which could easily be duplicated, or enlarged were reduced in capacity somewhat in the present installation. Other parts of the plant, which could not

easily be increased in capacity later, were actually made oversize in the present installation. Thus, the elements of the present plant appear, at first glance, to be a collection of structures, each designed on

FIG. 1.—Airview of the phenolic waste treatment plant of the Dow Chemical Company. (Courtesy Fairchild Aerial Surveys, Inc.)

a different basis of flow or capacity; but the plant as a whole actually is one which is quite flexible as to rate of present operation, and its capacity can be increased easily by adding duplicate or new elements.

The principal elements of the present plant (Fig. 1) are:

1. *The waste sewer systems,* collecting and delivering the wastes to a
2. *Pumping station,* including a small control laboratory and the pH control equipment, where the weak and strong wastes are mixed, conditioned and pumped through a
3. *26-in. steel pumping main,* in which the wastes are metered through an orifice plate, and delivered to a
4. *Settling tank,* containing a clarifier mechanism. The settled wastes flow by gravity through a 30-in. steel main with 16-in. cast iron branches to the two
5. *Trickling filters,* each of which has a power-driven rotary distributor. The effluent from the filters flows by gravity from center collection galleries through a
6. *30-in. and 36-in. outfall sewer* to the
7. *Outlet gate structure,* where the plant effluent is carried a short distance in an open ditch and discharged into
8. *Effluent ponds,* which have an area of 38 acres and from which the treated wastes are discharged into the Tittabawassee River.

Waste Sewer Systems

There are two sewer systems used to collect and deliver the wastes to the treatment plant. The first, which we shall call the strong wastes system, was in use prior to the construction of the treatment plant. It received the strong acid wastes and discharged them into one of the waste ponds. This system and its pond were incorporated in the general waste treatment program. The new work involved building about 325 ft. of 10-in. cast iron pipe from the pond to the new pumping station building.

The other sewer system, built to collect the weak wastes, involved much more work. As a backbone for this system, it was decided to use one of the other two existing sewer systems. In order to do this, many sewer changes were necessary. These changes involved cutting off sewer outlets from buildings whose wastes were not to be treated, and providing new outlets. All buildings whose wastes were to be treated had to be connected into the weak waste system. Inasmuch as all outside yard drainage around the buildings had to be collected, these sewers were designed as storm sewers, and are quite large, ranging in diameter from 10 to 24 inches. About 8 per cent of the total cost of the project was spent on these sewer changes.

This revamped sewer system discharged into a pond approximately 3,300 ft. north of the treatment plant site. At the outlet, the system consisted of a 24-in. sewer and a 36-in. relief sewer, each of which carried dry-weather flow. The design storm-flow capacity of these two sewers is 54 cu. ft. per second or about 36 million gallons per day (M.G.D.). The treatment plant program had to include provisions for carrying at least the dry-weather flow of these sewers to the plant site.

A 42-in. concrete trunk sewer, 3,300 ft. long, was built to carry the wastes from the outlet of the weak wastes sewer system to the pumping station. This sewer has a design capacity of 22 M.G.D. A steel sheet piling overflow weir was provided at the junction of the 42-in. and the 24-in. and 36-in. sewers to divert the excess storm flows into the effluent pond. This 42-in. sewer, with its appurtenant structures, represents about 11 per cent of the total cost of the project.

Pumping Station

The weak wastes are discharged from the 42-in. sewer into a small earth-bank pool at the pumping station. (Fig. 2) A steel sheet piling

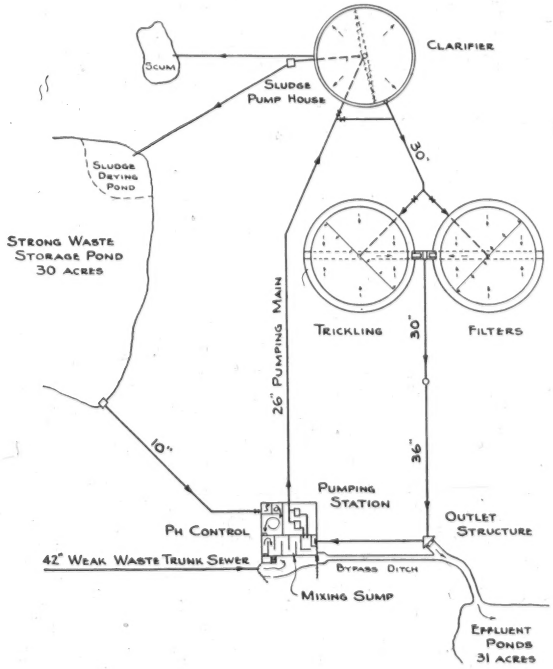

Fig. 2.—Flow diagram of phenolic waste treatment plant.

cut-off wall and overflow weir separates this pool from the open ditch into which the plant effluent is later discharged. One side of this pool is bounded by an open concrete tank which serves as a mixing tank and pump suction well. The weak wastes enter this tank through a coarse bar screen and a 42-in. square sluice gate. The bar screen is manually raked.

The mixing tank (Fig. 3) is provided with around-the-end type wood baffles which form a series of passes through which the wastes are directed to the pump suction pipes. In the first pass, directly opposite the weak waste entrance port, the strong wastes are also discharged through a 12-in. valved port from a conditioning tank inside the pumping station structure.

The strong wastes are first discharged by gravity, from the 10-in. pipe line previously described, through a throttling valve into a weir box inside the pumping station proper. The flow is measured through a hardwood V-notch weir, and discharged into a concrete mixing tank equipped with a turbine mixer. Hydrated lime is added at this point, from a gravimetric belt-type feeder, for pH control. From the mixing

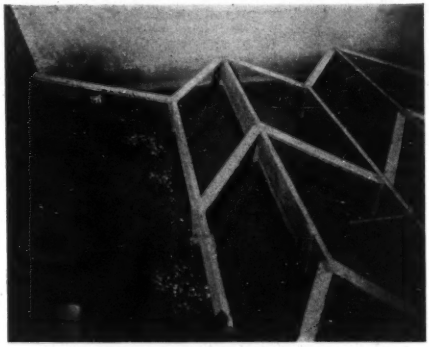

FIG. 3.—Mixing chamber, with strong waste entering through 12-inch port.

tank the strong wastes pass through a concrete conditioning tank provided with revolving paddle agitation, and thence into the baffled mixing tank, as described above.

The mixed wastes are pumped from the suction well to the settling tank by means of motor-driven centrifugal pumps. The present installation includes one 9,000 g.p.m. and one 5,600 g.p.m. pump, driven by 125 h.p. and 75 h.p. motors, respectively, operated at 690 r.p.m. on 2,300 volt, 60 cycle, 3 phase power. Automatic low-water shut-off control for these pumps is provided by means of induction relays, and electrodes submerged in the suction well. The pumps are started by manual control, with pump and suction line priming service supplied by a manually-controlled vacuum pump.

Inasmuch as the treatment plant is located more than three-fourths of a mile from any of the Company's service lines, pressure water for cleaning and flushing purposes is supplied by means of a 160 g.p.m., 3,500 r.p.m. pump with a 10 h.p., 440 volt motor. The feed for this pump is taken from the treated plant effluent. Water for the control laboratory, drinking purposes, and sanitary service, is supplied by a

small automatic piston pump from a deep well at the treatment plant site.

The pumping station substructure is of reinforced concrete with brick superstructure, steel sash, and cement tile roof deck covered with composition roofing.

The cost of the pumping station, including all equipment, piping, and valves, amounted to about 19 per cent of the total project cost.

26-Inch Pumping Main

The two waste pumps discharge into a 26-in. steel pipe line, which carries the wastes either to the settling tank, or through a 26-in. steel by-pass line to the settling tank effluent line. The pumping main is approximately 850 ft. long, including about 72 ft. of 30-in. cast iron pipe laid beneath the floor slab of the settling tank. The balance of the main is 26-in. outside diameter, by ⅜ in. thick, dipped-and wrapped welded steel pipe. The pipe was fabricated in 30-ft. lengths, and all field joints were shielded-arc welded. One expansion joint was provided, using a special coupling. A ¼-in. steel orifice plate, with bolted flanges provided with spreader bolts, was installed in the line at a point about 40 ft. from the pumping station.

The line is laid on a slight grade, pitching back toward the pumping station. A 10-in. blow-off and drain line at the low point permits draining the main and about one-half the volume of the settling tank into the same pond which receives the plant effluent. A 4-inch welded steel dipped-and-wrapped pressure water line was laid in the same trench with the waste pumping main; and it also can be drained into the effluent pond. The cost of these pipe lines represents 6 per cent of the total costs.

Settling Tank

The waste pumping main discharges at the center of the settling tank (Fig. 4). This tank is of reinforced concrete construction with

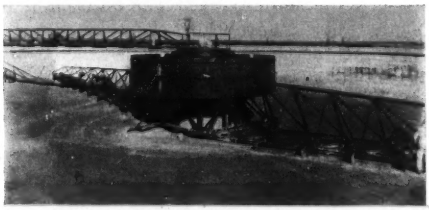

Fig. 4.—View of empty clarifier.

an effluent launder around the entire periphery, poured monolithically with the tank wall. The tank has an inside diameter of 140 ft., has an 8-ft. side water depth, and the usual 1 to 12 bottom slope. The normal water surface is 28.5 ft. above the average operating water level at the

waste pump suction pipes. A 60-degree, V-notch steel plate outlet weir is provided around the entire periphery of the tank. Surface scum and oil is prevented from overflowing this weir by means of a steel baffle plate partially submerged about 8 in. inside the weir, and supported by means of inverted V-shaped hangers welded to a steel angle ring anchored to the top of the tank wall. The weir plate is also bolted to this ring.

A clarifier mechanism, provided with skimming arms, is installed in the settling tank. Surface skimmings are discharged by gravity into a nearby swale, controlled by a manually-operated quick-opening ball valve. Settled sludge is removed by a piston pump and discharged into one of the waste ponds adjacent to the plant site. The design capacity of the settling tank was based on a 1-hour detention period for a 20 M.G.D. flow. Approximately 18 per cent of the total cost of the project was expended on the settling tank and its appurtenances.

Trickling Filters

The experimental work which led to the selection of the trickling filter has been mentioned. The next item of consequence was the selection of the type of filter media and the type of bottom underdrains. The data obtained from the experimental work, as well as the published data on filter design and operation, emphasized the importance of circulation of air through the filter bed.

Inspection trips were made to several municipal waste disposal plants where trickling filters were operating or were being built. Published data on the operating results, construction problems, and design features of trickling filters were studied, including the report of the committee of the American Society of Civil Engineers on "Filtering Materials." Tests were run, based on the above report, on coke, crushed blast furnace slag from six different sources, dolomitic limestone from two quarries, and limestone from three quarries. Inasmuch as shipment by boat was possible, with unloading facilities at the Company's own dock, the shipping cost was an item of ranking importance. Careful analysis of durability, size, shape and uniformity of crushed particles; surface contour of crushed media with relation to bacteria growth and the sloughing of this growth; ease and cost of handling and placing, the cost of the material, led to the selection of crushed blast furnace slag shipped in by rail.

The slag purchased was specified to have an average screen analysis as follows:

Screen Size, Inches	Percentage Passing
4	100
3½	95
3	60
2½	20
2	8
1½	Not more than 3

In order to hold the percentage of "fines" to a minimum, it was decided to re-screen the slag at the site as the last operation before placing it on the filters. It also appeared advisable to remove all pieces showing excessive iron.

Inasmuch as early completion was also deemed essential, endless belt conveyors were selected for unloading and placing the slag. A small hopper was built under an existing car siding approximately 800 ft. from the filters. A 75-ft. stationary conveyor, with reciprocating feeder, was purchased and erected. This conveyor discharged into a reconditioned gyrating screen. The screen discharged the fines directly into a truck, and the screen slag was discharged into a steel

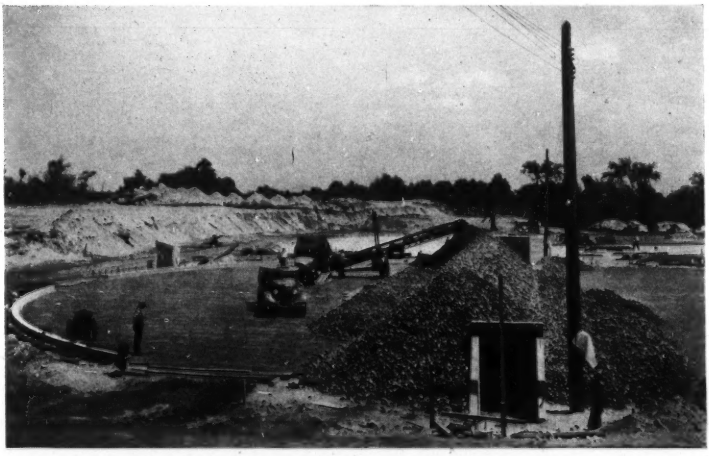

FIG. 5.—Trickling filter under construction.

hopper having a capacity of about 4 cu. yds. This was a salvage hopper on hand, which was reconditioned and fitted with a hand-operated under-cut bin gate. One and one-half yard trucks were loaded by gravity from this hopper. At the filters, a 25-ft. portable conveyor was used, with a special low hopper on the feed end, so that the trucks could dump directly onto the belt (Fig. 5). The entire handling setup was designed to handle 500 tons of slag in an 8-hour day. The final records show that 246 cars containing 14,113 tons of slag were unloaded, screened and placed on the filters at an average rate of 69 tons per hour. Of the total weight handled, 13,457 tons were actually placed on the filters; 455 tons, or 3.2 per cent, were screened out through the 1½-inch screen; and 201 tons, or 1.4 per cent, were removed as pieces containing excessive iron. The high-iron pieces were hand-picked off the stationary conveyor as the slag was elevated to

the screen. The screenings and iron culls were stock-piled, to be used later as road ballast, special concrete aggregate and other uses by the Company, so were not a total loss.

The two filters (Fig. 6) are somewhat unusual in design. The topography of the site was such that the filter bottoms were built on approximately the natural ground surface. The maximum cut was about 4 ft. and the maximum fill was about 1 foot. The 4-in. concrete slab bottom was laid on this prepared grade. Instead of pouring concrete walls to retain the slag media, the side slope of the slag itself is used as the retaining wall. This was done to reduce costs, and not in the hope that any material benefits in ventilation could be obtained. A

FIG. 6.—View of clarifier and filters.

45-degree side slope was used on the slag bed, and although this slope stands satisfactorily, the construction work indicated that a slightly flatter slope would be easier and faster to build. The filters have a diameter of 142 ft. at the top and 162 ft. at the bottom. The slag is 10.25 ft. deep at each side of the center gallery, with an average depth of about 9.75 ft. outside the gallery area, and the slag depth over the gallery roof varies uniformly from 5 to 7 feet.

Filter bottom tile are laid in mortar over the bottom slab to give 100 per cent coverage under the wetted area. The drains formed by these blocks slope toward the center gallery, which was built as a concrete rectangular box 6 ft. high and 4 ft. 8 in. inside. (Fig. 7) The ends of the gallery are open. The walkway space is 2 ft. wide, being separated from the collecting gutters on each side by a low concrete wall.

Filter blocks are also laid on the roof of the gallery. Effluent from these drains is discharged into the gallery gutters below. It is possible, therefore, to stand in the gallery, sight through any under-drain, and see daylight at the other end. Each drain can also be individually flushed. The longest drain is about 76 ft. long and the shortest 35 ft. long. It is believed that these filters have the very maximum possibilities for natural ventilation, due to these unusual construction features.

The filter influent is distributed over the beds through power-driven rotary distributors. Each distributor is 141 ft. in diameter and was designed for an average flow of 2.67 M.G.D. while rotating at ¾ r.p.m.; it serves an area of 15,800 square feet. Power drive was selected be-

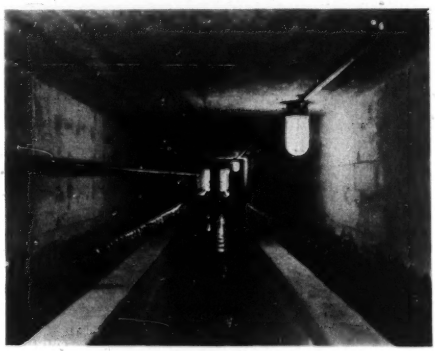

FIG. 7.—Filter gallery, showing drainage.

cause of the anticipated variation in rates of flow. The effluent is carried in the center gallery gutters to a manhole located on the common center line of the galleries and midway between the filters. The outfall sewer picks up the treated wastes at this manhole.

The filters complete cost approximately 30 per cent of the total costs.

OUTFALL SEWER AND OUTLET GATE STRUCTURE

The outfall sewer is 30-in. double-strength vitrified tile at its upper end, and is increased to 36-in. size at a manhole into which possible future structures may discharge. The sewer is approximately 610 ft. long. A sluice gate is provided at the outlet structure so that the sewer may be segregated from the open ditch and pond into which it discharges. A sewer connection from the outlet gate structure to the waste pump suction will permit pumping the entire effluent system dry. The outfall sewer and gate structure represent 3 per cent of the total cost.

Special Control Features

An operator is on duty at the plant only eight hours a day. The plant is visited by a control chemist every two hours of the other two shifts. In order to have a continuous record of operation, recording gages were used. Three liquid level gages, with 7-day charts, indicate and record the water level at the strong wastes and weak wastes influents at the pumping station, and the treated plant effluent. An indicating, recording and integrating flowmeter, also with a 7-day chart, records the flow through the orifice in the 26-in. pumping main. Mention has already been made of the automatic shut-off control for the large waste pumps.

The experimental work indicated the necessity for temperature and pH control, so recording meters were installed as a guide for this control. A Wheatstone-bridge type multipoint temperature recorder, calibrated for use with nickel resistance thermometers, records the temperature of flow at four key points in the plant. All of these four readings are recorded on one 30-day strip chart. In a similar manner, readings from three key points for pH control are recorded on a three-point potentiometer type hydrogen-ion recorder with a 30-day strip chart. All of the indicating and recording gages are flush-mounted on a steel panel in the control laboratory at the pumping station. These control features amounted to 1 per cent of the total cost.

All of the structural design work for the treatment plant was done by the Company's engineering department; and, except the earthwork for the preparation of the site and the installation of the 42-in. sewer, the construction work was done by the Company's construction department.

Operating Results

The plant was placed in operation the last week of October, 1937. During November and December of that year difficulties were encountered in obtaining sufficient heat in weak wastes. An open ditch was being used to convey weak wastes to the pumping station and this resulted in considerable heat loss. The 42-in. trunk sewer was completed the latter part of December. Many changes in the use of condenser water at several production plants and use of the trunk sewer increased weak waste temperatures to an average of 70.5° F. for the month of January, 1938. Continuous survey of the weak waste sewer system was necessary to eliminate fluctuating conditions. On the whole, very little trouble was encountered that might not be expected in placing any new plant into operation.

The operating data are summarized in Table I. By "gross" phenol is meant the bromine demand expressed as p.p.m. phenol. Many compounds other than phenol will brominate. The test is simple to perform and gives a ready indication of plant efficiency. All "net" phenol figures are from analyses after double-distillation, first from acid then from calcium carbonate. Phenol in excess of 20 p.p.m. is

TABLE Ia.—*The Dow Chemical Company Phenolic Waste Treatment Plant*
Monthly Averages of Operating Data

	1937		1938								
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Flows—Million Gallons per Day											
Weak waste by-passed to effluent pond	1.78	0.43	0.01	1.00	0.10	0.19	0.57	0.20	0.62	1.72	0.86
Weak waste to plant	6.22	6.10	6.24	6.09	8.28	8.98	11.42	10.84	10.97	11.50	9.36
Strong waste to plant	0.05	0.11	0.20	0.17	0.52	0.84	1.08	0.68	0.30	0.33	0.28
Effluent recycled	0.22	0	0.13	0	0	1.01	0.37	0.80	0.83	0.37	0.60
Total to filters	6.49	6.21	6.57	6.26	8.80	10.83	12.87	12.32	12.10	12.20	10.24
Effluent pond	8.05	6.64	6.45	7.26	8.90	10.01	13.07	11.72	11.89	13.55	10.50
Temperatures—Degrees Fahrenheit											
Weak waste	61	62	70	65	71	75	80	87	90	90	78
Mixed waste	61	62	69	63	69	73	79	86	89	90	78
Settled waste	—	59	66	61	67	72	78	85	88	89	77
Filter effluent	55	55	59	56	63	68	76	83	86	87	75
Pond effluent	43	37	37	38	46	52	62	71	77	76	63
Air	38	25	22	28	38	47	58	68	73	74	59

TABLE Ib.—*Monthly Averages*

	1937		1938								
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Analytical Data—Gross phenol—P.P.M.											
Weak waste	7	11	8	7	8	6	3	5	3	3	4
Strong waste	369	431	453	383	380	359	305	409	356	342	458
Mixed waste	13	17	20	17	34	36	30	24	8	11	14
Settled waste	15	17	22	18	31	35	30	24	7	9	13
Filter effluent	6	6	5	5	8	8	6	5	2	3	3
Pond effluent	5	6	4	9	5	4	4	4	2	2	2
Net phenol (by Gibbs)—P.P.M.											
Weak waste	4.1	5.3	3.6	3.8	3.9	3.1	2.1	1.5	1.1	0.8	1.3
Strong waste	207	242	283	229	221	190	174	227	162	165	273
Mixed waste	5.8	9.7	11.0	10.1	19.1	20.1	17.8	13.4	3.3	4.2	8.3
Settled waste	—	9.8	11.0	10.5	18.2	20.1	18.0	14.4	3.3	3.8	7.9
Filter effluent	1.3	1.3	1.0	2.0	2.2	2.3	1.6	0.68	0.10	0.08	0.18
Pond effluent	1.7	0.73	0.31	1.45	0.92	0.11	0.08	0.02	0.02	0.02	0.01
5-Day B.O.D.—P.P.M.											
Strong waste	703	759	846	968	745	635	479	656	634	538	820
Mixed waste	34	—	64	68	98	98	90	68	34	30	49
Settled waste	34	55	66	68	93	83	63	60	32	26	43
Filter effluent	21	16	21	15	19	18	17	20	7	4	8
Pond effluent	19	15	16	17	14	10	9	8	7	4	4
Total Cl as NaCl—P.P.M.											
Filter effluent	657	1310	1560	1112	1315	1680	1516	1160	782	761	789

Note: Approximate pH of wastes is as follows: Strong waste = 1.8, Weak waste = 7.0, Mixed waste = 6.5, Filter effluent = 7.5.

TABLE Ic.—*Monthly Averages*

	1937		1938								
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Quantitative Data—Phenol (by Gibbs)—Pounds per day.											
Total Phenol to System	373	526	601	580	1403	1802	1937	1478	338	438	716
Mixed waste	314	507	602	548	1400	1817	1932	1480	333	427	708
Settled waste	314	507	602	548	1328	1817	1932	1480	333	387	675
Filter effluent	70	67	55	104	161	208	172	70	10	8	15
Recycle	2	0	1	0	0	20	5	5	1	0	1
Weak waste by-passed	61	19	0	32	3	5	10	3	6	11	9
Pond influent	129	86	54	136	164	193	177	68	15	19	23
Pond effluent	114	40	17	88	68	9	9	2	2	2.3	0.9
B.O.D.—Pounds per day.											
Mixed waste	1840	—	3560	3550	7200	8850	9660	6980	3430	3055	4180
Settled waste	1840	2850	3560	3550	6830	7500	6760	6160	3230	2655	3680
Filter effluent	1137	828	1150	783	1390	1625	1825	2055	707	407	684
Pond effluent	1408	830	860	1030	1040	835	981	782	694	452	350
Filter Rates.											
M.G.A.D.	9.0	8.3	9.1	8.7	12.2	16.2	17.9	17.0	16.8	16.9	15.6
Lbs. of Phenol removed per 1000 cu. ft. per day	0.81	1.46	1.81	1.47	3.86	5.33	5.82	4.67	1.07	1.25	2.18
Lbs. of B.O.D. removed per 1000 cu. ft. per day	2.33	6.68	7.98	9.16	18.00	19.45	16.35	13.60	8.34	7.44	9.90
Phenol Disposal—Percent of Total of System.											
Clarifier	0	0	0	0	5.1	0	0	0	0	9.1	4.6
Filters	65.4	83.7	91.0	76.6	83.2	89.3	90.8	95.4	95.6	86.5	92.2
Effluent ponds	4.0	8.7	6.1	8.3	6.8	10.2	8.7	4.5	3.8	3.9	3.1
Total	69.4	92.4	97.1	84.9	95.1	99.5	99.5	99.9	99.4	99.5	99.9

determined by bromination of distillate. On lesser amounts, the determination is made by the Gibbs colorimetric method. Phenol, chlorphenols and cresol, together with a number of other ring compounds with a free hydroxyl group will show a color reaction in this test. Samples for analyses are taken every two hours and composited for the twenty-four-hour periods. Additional spot samples are taken every morning to check composite analyses. B.O.D. results are on spot samples taken three times a week. Dilution water is made by aerating distilled water, adding 300 p.p.m. $NaHCO_3$, and seeding with river water instead of sewage.

The clarifier, while not performing the work comparable to a sewage plant primary settling tank, has served its purpose very well. When lime is added to strong wastes to bring pH above 6.0, an iron hydrate floc results; during such times, the clarifier removes many inorganic solids and such organic matter as is held in suspension or emulsion. As a general rule, sludge is pumped but once a day and does not usually run over 1000 gallons per day. This sludge is drained to a small shallow pond adjacent to the strong waste storage pond where it is dewatered by evaporation and drainage through a sand dike. Since sludge is such a minor problem, analyses for suspended solids are not made. An average of 8.4 per cent of the B.O.D. is removed by the clarifier. There is very little, if any, phenol removal in this unit. The clarifier serves to iron out changes by virtue of its detention time and it prevents short circuiting.

The filters have received many "shocks" and in their early growth days were rendered almost completely sterile several times by acids, caustic, and free chlorine. Sewer changes have eliminated many of these dangers, but there still exist occasional pH and organic load changes that might spell disaster for a less rugged process. These fluctuations have been ironed out and oxidized in the effluent ponds. The operation of this plant has shown that a well-seeded filter will withstand sudden pH and toxic compound "shocks" with remarkable ability and will quickly recover to former efficiency.

The filters slough continuously and have never shown any indication to pool except in a few very small areas where fine aggregate accumulated on the surface during construction.

It might well be asked why a ten-foot filter was built when sewage treatment practice leans toward beds of less depth. The purpose of this plant from the outset was to produce the best effluent possible at least cost. In order to save cost on filter area a relative high rate of surface application was found to be possible, provided sufficient filter depth was available to attain the effluent thought to be necessary. Greatly increased removals of phenol per cubic foot of filter body can readily be attained by high rates of application on shallower beds, but the quality of the effluent deteriorates. It must be remembered that, unlike domestic sewage, practically all of the organic matter contained in these wastes is in true solution.

The results of analyses of samples taken at various filter depths are shown in Table II.

TABLE II.—*Phenol Remaining at Various Filter Depths*

Average Rate = 15.5 M.G.A.D.
Average Effluent Temp. = 75° F.

	Phenol by Gibbs Method
Filter Top	12.2 p.p.m.
5.5-ft. Depth	1.9 p.p.m.
6.5-ft. Depth	1.3 p.p.m.
9.75-ft. Depth	0.41 p.p.m.

From these average analyses, it can be seen that the last 3.25 feet produce an effluent that is 68.5 per cent better than the effluent from the first 6.5 feet. Each foot of filter is shown to remove about 30 per cent of the load applied to it.

Of special interest may be the fact that there is no filter fly problem at this plant. The construction features of the gallery and side slope make an ideal breeding place for filter flies, but apparently there is sufficient para and ortho- dichlorbenzene present to prevent development.

The effectiveness of the effluent storage ponds is clearly shown in Table I. An additional 17-acre pond was added to the 21-acre pond on May 18, 1938. It is estimated that these ponds provide about 48 hours detention time at a flow of 10 M.G.D. If the ponds can not oxidize the sloughed material from the filters as fast as it is accumulated and become septic, it is intended to lower the pond levels and allow this sludge to dry to a cake which can be scraped or floated off.

It will be noted that some effluent has been recirculated. In the experimental plant it was found that recirculated effluent seeded the influent to such an extent that as much as 50 per cent phenol reduction was experienced in the settling tank. Loss of heat does not permit recirculation during the colder months and effluent was used during the warmer months to make up weekend flows to a constant pumpage rate. The effect of recirculation has not been clearly indicated in the full-scale plant.

In conclusion it may be stated that the plant described has more than accomplished the purpose for which it was designed.

Operators' Reports and Suggestions

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STARTING A NEW SEWAGE PLANT *

By Frank Woodbury Jones

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"Where shall I begin, please your Majesty?" he asked. "Begin at the beginning," the King said very gravely, "and go on till you come to the end; then stop."

Molière wrote: "It's a long road from the inception of a thing to its realization." The truth of this is no better illustrated than in the elimination of sewage pollution. We shall therefore draw a veil over the many years which usually elapse between the date of the first order to "cease pollution," and that set for the completion of the treatment works contracts. The biennial changes of local governments, the succession of engineering investigations and reports, the law's delay, the uncertainty of financing, and procrastinating public opinion, all contribute toward postponement of that desired consummation, when odors cease from troubling and the weary may find haven for fishing and bathing.

"The beginning is the chiefest part of any work," and "What's well begun is half done." However, to make a good beginning in the operation of a sewage treatment plant is not always so easy as some suppose. True, it is a simple matter to open a valve and fill a tank with sewage, but it becomes more complicated if the sludge deposited therefrom fails to stay at the bottom, or refuses to behave itself seemly in the digesters.

The question might properly be asked: "What should be observed generally in starting the operation of a new sewage plant?" Cicero advised: "In all matters, before beginning, a diligent preparation should be made." This is highly important, and part of such preparation in starting a sewage plant should be directed toward making the operation satisfy three demands, namely: Political Demand; Economic Demand; and Oxygen Demand.

Political Demand.—The first step in satisfying the political demand is the selection of proper personnel, and this is true to some degree whether the works be the one-man size primary tank of a small borough or the large activated sludge plant of a metropolis. It appears that the era when the dog catcher or street sweeper would take a few hours per week for a look at the town nuisance is a thing of the past.

* Presented at the Twelfth Annual Conference of the Pennsylvania Sewage Works Association, State College, June 10, 1938.

In spite of this advance, there is, however, still a tendency to award jobs to the faithful, irrespective of qualifications. The licensing of operators should militate somewhat against such practice and should be most effective where the personnel is limited to from one to three men. When, however, laborers and attendants not requiring licenses are required, a part of the "diligent preparation" lies in selecting able-bodied and active men whose interest extends beyond the pay check.

The large plant, preferably, should be in charge of a sanitary engineer and chemist, although the highly mechanized modern plant needs the services of a good mechanic and electrician as well. The mechanization trend demands that the operator of a one-man plant be a "jack of all trades." Where there are three or four men, their abilities should vary and include, if possible, a man mechanically inclined, one who leans toward landscaping, and one who can give a hand at most anything. In any event, every sewage treatment plant, irrespective of size, should be under technical supervision, either full or part time.

Another factor in satisfying the political demand is the maintenance of proper relations and contacts between the plant superintendent and governmental agencies, both local and state. The borough or city administration is entitled to know what is going on at the sewage plant, whether the officers be vitally interested or not, because in these days people who spend money for improvements are likely to inquire how the investment is making out. It is obvious, also, that close co-operation between the operator and state officials should result in broadening the outlook of the local man, and in adding experience to the government man, and thereby pay dividends which may be reinvested in improved plant production.

Economic Demand.—The economic demand is closely related to the political demand, particularly in respect to financing. It is axiomatic that no sewage plant can operate without adequate funds, for even engineers admit now that they cannot design and build treatment devices that will operate automatically and without expense.

The financial needs should be carefully estimated and provided for before operation begins. In recent years the use of sewer service charges has gone far toward elevating the status of the sewage plant and making it a going concern. It is true that many regard this service charge as merely another tax, and in most instances the enabling ordinance encounters delay from all manner of opposition. However, once the legislative Rubicon is crossed, this method of financing has been found practicable and effective. Outstanding injustices can be corrected, and much can be done by the administrative agency to inform the public, establish confidence and win support.

A sewage plant should be run economically but not parsimoniously, and the time to establish a policy is at the start. All personnel should receive compensation adequate to and commensurate with the task. The grounds should be kept trim and attractive, and, of great importance, the equipment should be maintained in first class repair and

appearance. In this manner the plant will last longer, and every year its life is extended there is a saving which will far exceed the maintenance cost of material and labor. If such work is started at the beginning of plant operation, there is more likelihood that it will be continued.

From the outset, the operator should plan to eliminate all unnecessary expense. On a small plant costs are fairly well established, but on a large plant economies can be practiced which will lead to substantial savings. This is particularly true with power. By carefully watching the demand charges, and by avoiding, where possible, the use of too many motors simultaneously, the savings over a period of time will be considerable. In this connection, wattmeters can be installed temporarily, and power analyses made. From such analyses, actual operation requirements can be correlated with power needs and savings calculated.

Another economic demand may be met by a careful study of the gas situation. In most of the modern plants where digestion is part of the process, the sewage gas is trapped and utilized at least to heat the digesters. Use of the gas in the laboratory, heating furnace, or for the production of power may or may not be economical, but the possibility should be studied and evaluated.

Most laymen see in sludge the panacea for all farming ills, whereas the operator usually finds in sludge his greatest headache. However, the economic features of revenue from sludge should not be overlooked, although it should be stated that past experience points to serious doubt as to any real profit in the receipts. On the other hand, there is a certain psychological value in showing a cash income.

Great progress can be made toward satisfying the economic demand if, at the start, adequate supplies are on hand to maintain the operation and preserve the structures. It is the duty of every operator to keep the necessary materials well stocked. He should run the plant, and here is one opportunity for him to assert his prerogatives, and convince his superiors that genuine economy results from proper preservation and upkeep.

Oxygen Demand.—The oxygen demand in this discussion refers to the plant production as a whole. Every operator, as soon as he assumes charge, should remember that the first objective in operating a sewage plant is to produce an effluent commensurate with the design. To this end the personnel should be carefully instructed in their duties, and frequent checks made to note their actual performance. If the order calls for raking the screens every hour, they should be raked every hour until the need for a different schedule has been proved. Similarly, all routine duties, such as sampling, lubricating, meter reading, and the like, should be done on schedule, and there is no better time to begin than at the beginning.

The care of mechanical and electrical equipment is essential to its functioning and continuity of service. The manufacturer should be given opportunity to furnish directions for operation and maintenance

and, if possible, he should give detailed instructions. The matter of lubrication, for example, may make or break a piece of machinery. If the manufacturer's recommendations are disregarded he cannot be blamed for possible failure.

A small plant may be placed in service as a whole, although it is best, where complete treatment is used, to bring in one device at a time, especially on the larger works. Valves will be found requiring repairs; pipes will develop unexpected leaks; stoppages will be found; some equipment, in spite of inspection, will require adjustment; electric wiring may have developed shorts on standing; and any one of a number of happenings may cause delay and worry.

No plant should be started until there is some definite assurance of continuity of operation. It is folly to start settling tanks unless there is some place to put the sludge, and a digester full to overflowing, with not even a high river or a lagoon in sight, is tragedy beyond compare.

Close observation of the way in which the various devices function should be made from the very beginning for the purpose of noting accomplishments and improving them if possible. No set rules can be laid down to cover all cases. The presence of slugs of iron waste may make it necessary to replan the whole sampling schedule and methods of analysis and control. Digesters may foam or behave out of reason for no apparent cause. Consequently, there must be caution combined with study. Some sewage will develop odors for no explainable reason, and neither the designer nor the operator is to blame. Methods of control, therefore, must be devised and practised. It may be that a plant will click in all particulars from the start, and this is true in most cases. When, however, a number of unexplainable and unexpected happenings occur, there develops either a good operator or a plant of ill repute.

One or two suggestions may help relative to sludge digestion. Don't start the tank with too heavy a load; try to get digestion under way as soon as possible. Where a digester is not equipped with an auxiliary oil burner, temporary heat may be provided by using a contractor's coal-fired boiler, set up out of doors. Until digestion is well established, the gas line should be parted in such a manner that any possible foam and froth developing in the early stages will not get into meters and control equipment. When digestion has proceeded to the point where there is enough burnable gas to supply heaters, the piping can be reconnected. This simple precaution may save a lot of grief. A temperature of 90 deg. F. appears to give maximum gas production. The writer has never used lime in starting a digester, and has found that if an alkalinity of 1500 p.p.m. or over can be maintained, digestion will proceed normally and effectively. At the start the gas is high in carbon dioxide. In order to determine when it is burnable, a simple test may be made by collecting a nessler tube full, putting in a little caustic soda, closing with the thumb, shaking and opening the tube under water. From the amount of contraction the percent of carbon dioxide may be fairly approximated. If the carbon dioxide is 40 per cent or less, the sewage gas should be suitable for continuous use.

It is to be expected that, in these days, when even the small plant is highly mechanized, some difficulties will be experienced at the start. The operator is cautioned against hasty condemnation, especially where the equipment is new to him. A complete understanding will usually result in satisfactory performance.

Laboratory control should be representative and adequate to the plant, but not necessarily elaborate. From the very start, careful scrutiny should be given all results, and investigations should be made to determine whether the sampling schedules and methods of analyses depict actual plant conditions. A mass of inaccurate and unrepresentative data is worse than useless.

A simple, daily diary of events should be started with the plant and carried along without interruption. Recorded observation of plant conditions and performances may be of great value in combating possible future litigation.

The oxygen demand can best be satisfied by constant care and attention to equipment and by employing those methods of operation which develop maximum performance in the progressive stages of treatment.

Unexpected Happenings

A paper on beginnings would not be complete without reference to some actual occurrences causing chagrin and wonderment. A large gate valve refused to open. Digging up and disassembling disclosed a six-foot length of 4 by 4 timber lodged in the bonnet.

The erratic performance of a twin dosing tank was traced to a cracked cross in the air feed. Many instances of peculiarities in pipe lines have been found attributable to misleading valve indicators. In this connection, it is well always to check the indicators and see that the wheel arrows point in the right direction. Limit switches on large electrical gates should be examined frequently. When a blower was started recently, a foreign sound, followed by investigation revealed a cement sack in the impellors. Result: A sprung shaft and three weeks of delay. Concrete has the habit of turning up in most unexpected places, as all operators well remember. It is surprising also into what small and unusual crevices and crannies stray lumber can hide. Every operator has had experiences which have startled and baffled him. In most instances, also, the remedy has been simple once the source of the trouble was discovered.

Conclusion

Some operators are "keen in commencing, negligent in concluding." It has been truly written that "a fool beholdeth only the beginning of his works, but a wise man taketh heed to the end." It is the duty of the sewage plant operator therefore, once his task is begun, not to lose interest, but to carry forward, striving only for the best so that the unclean sewage brook may be regenerated and join the brimming river with its past forgiven and forgotten.

OPERATION OF INTERMITTENT SAND FILTERS

Excerpt from "The Digester" for August, 1938

By W. H. Wisely

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The intermittent sand filter has been used in sewage treatment for many years. Today it is employed mainly for institutional and small municipal installations where the location is such that winters are not severe. There are 17 Illinois municipal sewage treatment plants using intermittent sand filters at this time.

Their Function.—Sand filters, like activated sludge and trickling filter units, are "secondary" treatment works, their purpose being to remove and transform the non-settleable and dissolved sewage solids remaining in the sewage after primary sedimentation.

How They Work.—Settled sewage is discharged at various points on the sand surface by a system of troughs or pipes. The sewage then passes down through about 24 in. of sand and 12 in. of graded gravel to a system of open-joint underdrains which collect the filtered effluent and discharge it to the stream.

Purification results in two ways, (1) by action of bacteria and other organisms which can only be seen with a microscope and which live at the sand surface, consuming some of the sewage solids and changing them into substances not objectionable and (2) by straining out the larger sewage solids, retaining them as a mat at the sand surface.

You will recall that the activated sludge process and trickling filters also use the tiny "bugs" or "workmen" to carry on the purification work. You will also remember that these "bugs" must have oxygen (from the air) to be able to live. In the sand filter, the "bugs" are given contact with air by providing for intermittent dosage of sewage by means of a dosing tank and automatic siphons, so arranged that the filter beds are dosed alternately.

The sewage solids strained out at the bed surface will eventually form a mat and will, of course, gradually reduce the rate at which the sewage will filter through. If allowed to accumulate too long, sewage will be held on the bed throughout a complete dosing cycle and the "resting" period will be eliminated. The operator must avoid this by developing a cleaning schedule to fit the rate of surface mat accumulation. The beds are cleaned by placing one of the units out of service (putting all the settled sewage through the remaining beds), allowing the mat to dry, and then raking off the dried mat. A thin layer of sand will be removed and discarded with each cleaning. A bed needs cleaning if sewage remains pooled at the surface 4 to 6 hours after the bed is dosed.

Routine Operation Suggestions

1. Since the biggest item of sand filter maintenance is removal of the surface mat of sewage solids, it behooves the operator to obtain

best possible efficiency from the settling tanks. Absence of settleable matter in the sewage applied to the filter lengthens the time of filter operation between cleanings, saving labor. Get all the work you can from the primary tanks!

2. Make a weekly inspection of the dosing siphons and piping, making certain that all air and sewage passages are clean and clear.

3. Accumulations of grease and slime on dosing tank walls should be carefully removed to avoid discharge of this material upon the filter.

4. Maintain proper adjustment at the discharge openings on the distribution system so that reasonably uniform dosage over the filter results.

5. When pools of sewage remain on the filter surface as long as 4 or 5 hours after dosage, the unit should be placed out of service, permitted to dry and the surface mat of sewage solids removed by raking or light scraping. Avoid removal of more than ¼ inch of sand. If possible, develop a cleaning schedule requiring that a minimum of beds be out of service at any time. Never delay cleaning until surface pools cover parts of the bed during the entire rest period between doses. The material removed in cleaning may be used as fill.

6. After removal of the surface mat and any "volunteer" weeds and grass, the sand surface should be carefully levelled before return to service.

7. Deep plowing of sand filters is not advised. When very fine sand is used, the material may become compact in which case the bed may be harrowed or lightly plowed to a depth not to exceed 6 inches after all foreign matter has been removed from the surface.

8. A small amount of new sand should be added every two years to replace that lost in cleaning.

Winter Operation.—In severe climates, ice formation and snow drifts on the beds may interfere with filtration. Regardless of which of the following winter procedures is adopted, every effort should be made to begin the winter season with thoroughly clean beds.

1. Although filter efficiency may be slightly impaired, removing enough of the beds from service to shorten the rest cycle of those in operation is suggested. The sand surface will freeze solid during a long rest period but if this time is reduced so that only a light frost takes place between doses, filter operation should not be interrupted. The light freezing actually "heaves" the sand, thus loosening it so that the sewage will pass through more quickly. This procedure requires careful attention and advantage should be taken of every opportunity for cleaning.

2. An alternate procedure is to form ridges 12 in. high and spaced 2 ft. apart, the ridges radiating from the sewage discharge points. Formation of 12 in. piles spaced 3 ft. apart over the surface of the filter will give the same result. The ridges or hills hold the ice sheet off the bed surface, permitting the sewage to spread over the sand beneath. Filters should not be levelled in the spring until accumulated solids are removed.

FIRST YEAR'S OPERATION OF THE ELIZABETH, N. J., JOINT MEETING SEWAGE TREATMENT PLANT SERVING TWELVE MUNICIPALITIES IN ESSEX AND UNION COUNTIES

By Leslie E. West

Chief Engineer of the Joint Meeting,

105 Mill Road, Irvington, N. J.

The Joint Meeting sewerage system serving at present twelve municipalities in Essex and Union Counties, N. J., is located in the most densely populated section of the state, in the drainage areas of the Elizabeth River and the east branch of the Rahway River.

As far back as 1900 seven municipalities entered into the original "Joint Meeting" and constructed a trunk line sewer to tide water with dilution as the method of disposal, having a total capacity of some 21 million gallons daily.

The capital cost of this trunk line was paid for on the basis of the percentage of the capacity reserved by each municipality in the line, taking into account the mileage of sewer used; and maintenance was paid for on the basis of an annual assessment divided equally between the contracting municipalities.*

For twenty years this arrangement worked very well until the abnormal and entirely unexpected growth in population of the area served, caused overtaxing of the sewerage facilities and necessary enlargement. The actual construction of the enlarged collecting system was begun in 1926 and completed in 1932; and of the treatment plant in 1931 and 1937. The six years' time expended on plant construction involved a three years delay because of financial difficulties. Completion of the work was accomplished through the assistance of the Public Works Administration.

Plant Buildings

The plant proper is located in the southeastern or Bayway section of Elizabeth, about ¼ mile inland from Arthur Kill. The site is approximately 28 acres in area. The several service buildings and their principal functions are: Screen House—housing the fine screens, screening and grit conveyors, ejectors, screening storage bin; Triturator and storage rooms for supplies; Administration Building and Pumping Station—containing main switchboard, grit chamber and tank dewatering pumps, primary sludge pumps, air compressors, central heating plant, tool and stock rooms, offices, laboratory, committee room and record vault; Venturi Meter and Chlorination Building—housing Venturi meters and registers, dewatering pumps, storage room and chlorination room; Sludge Pumping Station—containing triplex sludge pump for moving sludge from thickener tank to storage,

* Under the present contract the maintenance assessment is based on the percentage of flow from each municipality.

or for transferring sludge to centrifuges, centrifugal sludge pumps for loading stored sludge into barges for disposal at sea, chemical feed machine, gas incinerator, stock and spare parts room; Centrifugal Building—to contain centrifugal dewatering machines, effluent treatment tank, storage tanks and various pumps (under construction); Repair Shop—temporary building for repair of equipment and construction of various tools and operating devices—forge and anvil, welding and cutting tools, drilling and grinding machines, pipe tools, etc.

Operation

A number of factors have important bearing and effect on operation.

Gravity Flow.—All sewage flows into the plant through the tanks to the outfall by gravity. Pumping from the tanks is necessary only for repair work on tank equipment or mosquito and odor control of idle tanks.

Available Extra Capacity.—The plant for the most part was designed to handle an ultimate flow of 172.5 m.g.d. Settling tank capacity now provided is sufficient for 100 m.g.d. at 2 hour detention, or 50 m.g.d. at 4 hour detention. Present flow to the plant averages 28 m.g.d. (1938) and an estimated population of about 300,000 is connected.

The type of sewage treated at the plant is classified as medium strength domestic sewage. Very little industrial waste is present. Practically all of the sewage originates in separate sewerage systems, although some added by the City of Elizabeth comes from combined sewers. For the most part the sewage arrives at the plant in a relatively fresh condition and consequently has but little odor.

No by-passes or other outlets for the diversion of flow from the plant exist—accordingly a wide fluctuation of flow is handled by the plant.

The Concentration of Sludge.—The disposal of sludge is undoubtedly the most important function of the treatment process, as well as the most costly. The cost of operation is directly related to the volume of sludge produced and barged to sea. In the operation of the plant it has been possible to readily reduce the percentage of moisture of the sludge from between 94 and 95 per cent as collected fresh, to between 90 and 93 per cent as pumped to the barge. The reduction of volume thus afforded has been the chief source of economy at the plant.

Plan of Plant Operation

The plan of operation practiced at the present time provides for continuous removal of screenings and grit 24 hours daily and of the other operations as far as possible during the day shifts, with the exception of sludge loading to barges, which depends upon numerous variable factors and may be either day or night.

In sequence, the following brief description covers current practice.

Screening and Grit Collection and Disposal. *Bar Racks.*—Cleaned

hourly or as required. Large trash and rags disposed of as fill in meadowland. *Fine Screens*—one usually operates continuously at about 7-minute intervals, bringing up material to the conveyor belt beneath, from whence it is transported to pneumatic ejectors holding 17 cu. ft. each. By compressed air at 60 lbs. per sq. in. initial pressure, screenings are lifted into the elevated storage bin feeding the triturator. An alternate method of disposal of screenings is by being mixed with grit and pneumatically deposited as fill in the adjacent meadowland; the triturator is operated once during each of the three 8-hour shifts for about an hour to grind the screenings accumulated at the time which are reintroduced into the sewage. *Grit Collection*—is by means of Link-Belt Straight Line equipment and inclined conveyor screws to a horizontal conveyor belt similar in arrangement to that provided for the screenings. From the grit conveyor belt, a duplicate set of pneumatic ejectors discharge the grit by means of a 6 in. cast iron pipe to the meadowland for fill.

Settling Tank Operation.—The sewage flow is generally divided into two of the four settling tanks. Under average conditions of daily flow the detention period is approximately 3¼ hours. The units consist of four rectangular tanks, each 280 ft. long and 75 ft. wide, with average depth of 13 ft. Adjustable effluent weirs between the elevations of 3.0 and 6.4 provide additional tank capacity for increasing the calculated detention time. The present setting of the weirs is at elevation 4.0 to curtail the slow velocities which would result in the influent flumes under the low flows now prevailing; each tank is equipped with perforated inlet baffles for flow distribution, scum baffles in front of the effluent weirs, and scum removal sumps for withdrawal of scum by means of pneumatic ejectors to the sludge thickener; Mieder type traveling bridge sludge collector which scrapes the bottom and skims the top; lateral sludge sump and Link-Belt Sludge cross-collectors; sludge and tank dewatering pipes, valves and other appurtenances. At highest weir settling the capacity of each tank is 12.5 m.g.d. at 4-hour detention—at elevation 4.0 a flow of 10.5 m.g.d. corresponds to a 4-hour period.

The Mieder traveling bridge sludge collectors are machines of the tractor crane type having a clear span of 75 ft. In a forward direction the scraper blade can be easily adjusted to the surface elevation of the tank and the scum swept from the surface and concentrated in the narrow space between the blade and the scum baffle at the effluent end of the tank and removed by compressed air; on the return trip the blade is lowered to the bottom of the tank and all the settled sludge drawn to the cross-collectors and sump for withdrawal and discharge into the sludge thickener or storage tanks direct, as may be desired.

In skimming, the velocity of travel is between 5 and 10 ft. a minute, in sludge collection between 2 and 3 ft. a minute; and cruising, when skimming is not required, or when it is desired to transfer a machine to another tank, as high as 75 feet a minute.

The scraping blade is formed of ½ in. by 6 in. gum rubber which in

use is compressed against the tank floor, the weight of the blade being carried by steel wearing shoes which ride on steel rails imbedded in the tank floor and flush with it. Besides absorbing the wear, this arrangement permits smooth action of the scraping blade, with no noticeable agitation of sludge.

In operation it has been found practicable to remove the sludge during the 8-hour day shift only. About five complete trips are sufficient to satisfactorily remove all of the sludge and the average results of removal of suspended solids are above 60 per cent during the year; after passing over the effluent weirs, the clarified sewage is conducted through an effluent channel through twin 84 in. by 42 in. Venturi Meters and a twin rectangular outfall sewer about a quarter of a mile long to the outfall diffusion chamber where it is discharged into the tidal current of Arthur Kill, some 20 feet below the surface. After a year's operation the Venturi meters operating on the clarified sewage have shown no signs of clogging, as compared with other Venturi meters on the collecting system measuring sewage, which require cleaning about twice a month.

Sludge Collection.—Barnes plunger type sludge pumps operate every day from 4 to 6 hours and withdraw the fresh sludge from the settling tanks and discharge it into the thickener or storage tanks, as desired. Usually two constant-speed pumps work simultaneously, delivering a rate of flow of sludge between 250 and 275 g.p.m. The average moisture content of this freshly collected sludge is between 94 and 95 per cent according to season. When samples taken indicate a sludge of 98 to 99 per cent, pumping is stopped.

Sludge Concentration.—It was originally intended to provide for and secure a thickened sludge by chemical means. It was soon found that a natural thickening action occurred in storage under certain control, and that a thick sludge was readily obtainable, sufficient to overtax the facilities provided for its removal; consequently the thickener tank does not operate as such, but rather as a receiving tank for fresh sludge where it can be carefully observed as to solids content, and a place where the scum ejected from the settling tanks can be intermixed with the sludge. From the thickener tank, sludge is lifted by a Marlow triplex sludge pump to either of the storage tanks, or delivered to the centrifugal building. Sludge is placed into storage until sufficient volume is present to fill a 3500-ton tank barge. Each tank is of circular concrete construction, 70 ft. in diameter, with an effective depth of 23.8 feet and having a total capacity of 626,000 gallons or 2730 tons. As an odor control measure, each tank is equipped with a floating cover which rests on the surface of the sludge and effectively eliminates contact with the outside air. The tanks are unheated and efforts are made to keep the sludge as fresh as possible. Little digestion takes place, except when the sludge temperature rises to 70 degrees F. in late summer. Gases evolved are vented to the atmosphere at an elevation of 30 feet above the ground, and have been unnoticed at ground level. During the cold season when 50 degree F. temperatures of sludge are re-

corded, practically no digestion occurs and little if any gas is evolved.

When freshly collected sludge is allowed to stand for any length of time, a natural separation of water from the sludge takes place. In an acid sludge at 55 to 60 degrees F. this stratification occurs at or near the bottom of the mass; in an alkaline sludge of any temperature or an acid sludge of 50 degrees F. or lower, the tendency of stratification is toward the top. By providing suitable arrangements for tapping this water at the elevation where it occurs, considerable reduction in volume is effected. Each tank is provided with an arrangement for withdrawing this water from elevations 11, 15, 18, 21 and 24 feet. It is proposed to add still another valve, at elevation 8, in the near future. Reduction of the original volume of from 25 to 40 per cent or even more is accomplished at the plant. The return of this liquid to the incoming sewage has had no noticeable ill effects on operation of this type of plant.

Sludge Loading Into Barges.—Loadings of sludge for disposal at sea are made about twice a month. The Joint Meeting leases a dock at the waterfront for this purpose, under agreement to load 3500 tons in 5 hours. Existing arrangements for loading consist of 2 American Well Works Centrifugal Pumps with 15 H.P. motors and rated at 2000 g.p.m. each, at a total head of 23 feet. Experience at the plant during the past year has indicated that a satisfactory pumping rate can prevail only on that sludge placed into storage recently, or when the moisture content and consistency compare with fresh sludge (that is above 94 per cent moisture). In operation this condition is sought by jetting the mass with water under high pressure. When, during the pumping, the sludge drops to 92–90 per cent water, heads due to friction in the discharge main are observed to increase, and total heads as high as 40 feet have been encountered in moving the material through the 4000-foot force-main to the dock.* Means for using compressed air as an auxiliary, for emptying the line to the dock, have been established and have proved very successful.

The tanks are "conditioned" by using a fire hose and water under high pressure to *stir up the mass for an hour* or so prior to the time of starting the pumps. When the rate of pumping is far below normal and the observed heads are excessively high, the pumps are shut off and compressed air brought into play to clear the line to the dock and lessen the resistance of the material in the pipe. The resumption of pumping is generally marked with a much higher rate of discharge until a return to the original state of affairs necessitates a repetition of the procedure. The *temperature* of the stored sludge has considerable effect upon the rates of pumping observed, the moisture contents of the sludges being constant. At 50 degrees F. a markedly reduced rate of pumping is noticed over that prevailing at 70 degrees F., accountable only as due to increased pipe friction. Winter loadings have required as much as 10 hours compared with 5 or 6 hours during the summer. To overcome this difference the Joint Meeting will alter

* *Ed. Note* (Due to high viscosity of 90 per cent moisture raw sludge).

the existing pumps to provide a capacity of 2000 g.p.m. each at 40 ft. instead of 23 ft. head.

Another operating difficulty was observed during the past winter, namely the freezing of the floating covers against the walls of the storage tanks, due to the fact that 16 feet of the stored sludge is above ground elevation and unprotected from the weather in any way. This condition prevents the emptying of the storage tanks of sludge for fear of leaving the floating covers without support and in danger of collapse, buckling or jamming. It is planned to suspend the covers each winter from the top of the tank walls and to float them off when all danger of freezing is past.

Barging to Sea.—At intervals of from two to three weeks, sludge in quantities of approximately 3500 tons is barged to sea for disposal. As loadings are dependent upon the operations of the owners of the dock, the barging contractor's commitments, the amount of sludge in storage, weather and the tide, it can readily be imagined that loadings may be scheduled for either day or night.

The disposal of sludge at sea has been practiced for many years by a number of parties. In the metropolitan area the Passaic Valley Sewerage Commission has been utilizing this method for about 15 years and the City of New York and the Joint Meeting for about 1 year each.

A joint study of the effects of discharging sewage sludge at sea upon the adjacent waters has recently been undertaken by the three above mentioned agencies with the co-operation of the Supervisor of New York Harbor. The results of this study are not available at the date of this report, but are expected to be reported on shortly. Of the costs of this method of disposal in comparison with others, it may be mentioned here, to be about 34 cents a ton, which includes labor, pumping, docking and barging costs.

Certain changes and additions to the plant have been made by the operating force as the result of experience during the first year. Some of these are:

Installation of an electric eye device to limit peak demands, by cutting automatic air compressors temporarily out of service; installation of heating facilities in sludge pumping station and pipe galleries; installation of triturator, with piping, storage bin and electrical work; installation of cast iron piping and control valves to permit adaptation of Marlow triplex pump to transfer sludge from tank to tank, or to centrifuges; installation of decantation valves and piping in tanks, also service piping (gas, air, water, etc.), guard rails, new pavement, drains, redecoration of buildings, etc.

Safety Organization.—Encouraged also by the Joint Meeting are efforts toward the safety of the visiting public and the operating force. The subject of safety is impressed on the minds of all employees of the maintenance department. A safety committee composed of 5 men elected by the employees, holds meetings about once a month, and discusses and submits reports concerning unsafe practices, suggested

plant improvements, such as machine guards, railings, fences, insulation, warning signs and so on, which after investigation by the Superintendent, are reported to the Commission's own safety committee for appropriate action. A number of safety devices are provided and the men are instructed in their uses. Most of the maintenance employees have completed courses of training in "First Aid" under the American Red Cross. A list of available safety equipment at the plant, or on the trucks of the Joint Meeting include: all service gas masks with hose and blower; safety belts; life preservers; first aid kits; stretchers and folding cots; all service explosive gas detector with safety lamp; carbon monoxide detectors; carbon monoxide ampules; hydrogen sulfide detectors; explosive gas indicators (portable); carbon dioxide fire extinguishers; large and small chemical fire extinguishers.

Number of Operating Force

The scheme of operation adopted is that in which as much work as possible is performed during the second or day shift. The first and third shifts are confined primarily to the operation of the screening and grit removal equipment. The total number of men employed in the operation of the plant, excepting the superintendent, is 22. Seven men cover the 1st and 3rd shifts and the balance of fifteen the day shift. The list of the various employees follows:

Executive Clerk	Sludge Station Operator
Maintenance Electrician	Regular and Relief Equipment
Master Mechanic	Operators 12
Chemist	Laborers 5

Plant and Operation Data

Sewage Flow—
- Average flow treated, 1937 ..... 25.8 m.g.d.
- Maximum daily flow, average ..... 40. m.g.d.
- Minimum daily flow, average ..... 18. m.g.d.

Coarse Racks—Screenings—15 cu. ft. per day average.
Fine Screens—144 cu. ft./day or 5.58 cu. ft./m.g.
Grit Chambers—242.5 cu. ft./day or 9.4 cu. ft./m.g.
Triturator—144 cu. ft. per day.
Primary Sedimentation Tanks—
- (*a*) Type and capacity—4 Rectangular Tanks, mechanically cleaned, Link-Belt equipment—each 75 ft. wide, 280 ft. long, 13 ft. deep.
- (*b*) Detention period—two tanks operating—
  - At average daily flow —25.8 m.g.d., 3.26 hours.
  - At maximum daily flow—40.0 m.g.d., 2.10 hours.
  - At minimum daily flow—18.0 m.g.d., 4.66 hours.
- (*c*) Sludge withdrawal—daily.
- (*d*) Scum removal—as required, average twice weekly.
- (*e*) Amount of sludge removed—74,175 gal./day, or 384 cu. ft./m.g.
- (*f*) Amount of scum removed—varies, estimated 40 cu. ft. per day.

Sludge Concentration Tank—
- (*a*) Type—Circular concrete tank 22 ft. dia., 14 ft. deep. Capacity 38,233 gals., with picket fence arrangement for mixing sludge and scum.

(*b*) Use—Control of sludge being placed into storage and point of adding scum or chemicals, when desired.
(*c*) Frequency of operation—daily.
(*d*) Amount of sludge handled daily—74,175 gallons.

Sludge Storage Tanks—
(*a*) Type—two 70 ft. dia., 23.8 ft. deep, circular concrete tanks with floating covers. Capacity each 626,000 gallons, or 2730 tons of sludge.
(*b*) Frequency of use—continuous.
(*c*) Reduction in volume effected. 24,175 gallons per day. Average percentage of volume reduction from original—30 to 35.
(*d*) Disposal of sludge—twice monthly by barging to sea.

Analyses Performed during Plant Operation

Hourly composited samples.

	Screened Sewage	Clarified Effluent
B.O.D.—five day at 20 degrees C.		
(*a*) Frequency of tests—daily.		
(*b*) Average during the year	193 p.p.m.	122 p.p.m.
(*c*) Maximum during the year	265 p.p.m.	170 p.p.m.
(*d*) Minimum during the year	150 p.p.m.	75 p.p.m.
Suspended Solids.		
(*a*) Frequency of tests—daily.		
(*b*) Average during the year	178 p.p.m.	62 p.p.m.
(*c*) Maximum during the year	274 p.p.m.	94 p.p.m.
(*d*) Minimum during the year	130 p.p.m.	45 p.p.m.

Summary of results covering first year's operation during the months May–Dec. 1937.

Population—present connected	300,000
Sewage Flow—million gallons treated per day, average	25.8
Gallons treated per capita per day	86
Detention period, settling tanks, hours	3.26
Screenings—average removal in cu. ft. per day	144.0
Cu. ft. per million gallons treated	5.58
Grit—average removal in cu. ft. per day	242.5
Cu. ft. per million gallons treated	9.40
Primary Sludge—from clarifiers daily, in gallons	74,175
From clarifiers daily in tons	309.
Tons of dry solids per m.g. as removed	.646
Percentage of moisture, dry basis	94.6
Percentage of organic material, average	75.83
Stored Sludge, as barged to sea—total tons barged during 1937	50,415
Percentage of moisture, average	92.0
Barged—in tons per m.g. treated	8.06
Electric Power Consumption—peak demand	
Kilowatts (limited by control)	60
Daily consumption, kilowatt hours, average	350
Average daily cost of power used	$10.
Average power cost per m.g. treated	$ 0.388
Cost of sludge barging—total cost of barging, including wharfage	$16,938.63
Cost per ton of sludge barged	.34
Total Cost of Operation—total amount expended at plant in 1937	$67,938.41
Actual cost per m.g. for the 8 months' use	10.97
Estimated cost of treatment per m.g. on 1 year basis	9.00
Cost per capita per year (1937)	0.23

COST OF OPERATION OF SEWAGE TREATMENT PLANT—1937

	Amount	Percentage
Administrative and Legal	$ 5,070.00	7.46
Automotive	300.00	.44
Barging	16,931.63	24.92
Equipment, Supplies, Contingencies	3,712.26	5.46
Electric Power	3,369.63	4.96
Fuel, Oil and Gas	1,000.67	1.47
Insurance and Bonds	1,006.55	1.48
Labor	24,515.95	36.09
Printing and Stationery	323.70	.48
Supervision, salaries	9,680.00	14.25
Water	1,445.58	2.13
Miscellaneous	582.44	.86
	$67,938.41	100.00

SUMMARY

Results obtained during the first part-year of operation have indicated the following:

1. Plant performance has been at all times equal to or better than the standards established by the designing engineers.
2. The Elizabeth River has been greatly improved in quality through the elimination of pollution, and the condition of Arthur Kill (the receiving stream) has shown signs of improvement also; not to the same degree, due to the unabated pollution from Bayonne, Elizabeth, Linden and Staten Island.
3. The costs of treatment have been reasonable in comparison to plants of similar size and indicate possibilities of further reduction in the future.
4. The amount of flow treated has averaged only about 1/3 of the present capacity and the plant has ample provision to take care of the Elizabeth flow when required to do so.

ANNUAL REPORT (CONDENSED), SEWAGE TREATMENT WORKS, CITY OF WORCESTER, MASS., FOR THE YEAR ENDING DECEMBER 31, 1937

BY JOHN H. BROOKS, JR.

Superintendent of Sewers

No material changes were made in the general method of plant operation during the year.

The control of the filter fly by flooding the filters was again practised, but the interval between floodings was increased from seven to ten days. Past experience indicated that this change would be beneficial to the filters. Irregular filter operation owing to a W.P.A. project prevents any direct conclusion as to 1937 operations.

The removal of dried sludge from the drying beds during 1934, 1935 and 1936 was accomplished under an E.R.A. or W.P.A. project, but in 1937 the continuance of this work was approved by the Federal authorities. Owing to inadequate operating funds, only a small part of the dried sludge could be removed during 1937. Careful cost records clearly indicate the absolute necessity of increasing the annual operating budget for this work; with this allowance, the cost of plant operation will be less than previous to the industrial depression.

Sewage Flow

The total sewage flow during 1937 was 8172.35 million gallons, a daily average of 22.39 million gallons. The recent repression is not reflected in this figure to an appreciable extent and the quantity of sewage is what may be considered normal.

Grit Chambers

There were removed 1058.6 cubic yards of material from 8.172.35 million gallons of sewage, representing an average of 3.51 cu. ft. per million gallons. Each chamber was flushed nine times during the year. The average cost of flushing the chambers was 43.1 cents per cu. yd. of material removed.

The sand filter, on to which these flushings are discharged, was partially cleaned in July. 472 cu. yds. of material were removed by welfare help at a cost of $234.91, representing an average of 49.8 cents per cu. yd.

Screening of Sewage

The new screen building was completed except for a small amount of painting and placed in use, May 26, 1937. There were removed from 8172.35 million gallons of sewage, 16,722 cu. ft. of screenings, representing an average of 2.05 cu. ft. per million gallons of sewage. This quantity of screenings is the smallest in any year since 1932.

Imhoff Tanks

There have been no changes in the routine operation of the Imhoff tanks nor any unusual incidents in connection wih their operation. Twelve and one-half years of operation have been entirely successful.

The sludge production was nearly 50 per cent greater than during the previous year while the total influent flow was about 2.5 per cent greater. The sludge production per million gallons of sewage treated averaged 1,957 gallons as compared with 1,367 gallons in 1936. The low percentage of volatile matter in dried sludge, 43.30 per cent in 1936, was further decreased to 40.80 per cent in 1937. The percentage of dried solids in the sludge was nearly the same as that of last year.

Trickling Filters

During the last three months of 1936, the results of filter operation were abnormally poor, owing to considerable pooling on the surface. This difficulty was partially remedied when the filters were harrowed in January and the quality of the filter effluent greatly improved.

From May to September, filter flooding for fly control was practised about once every ten days. This program, together with the stone removal, resulted in irregular filter operation from June through December.

While the average B.O.D. of the filter effluent is less than that of 1936, the nitrate nitrogen and dissolved oxygen contents of the effluent do not average as well. It is believed that the latter results can be attributed to the adverse operating conditions. The average relative stability of the effluent was improved as compared with 1936.

Secondary Tanks

None of the four secondary or final settling tanks were cleaned during the year; sludge was pumped once each week. During the summer months the sludge was pumped to the concentration tanks and during the remainder of the year, to the winter sludge bed area.

The average percentage relative stability of the final settling tank effluent was 90, a slight improvement as compared with 1936; suspended solids averaged 55 parts per million, the same as in 1936; biochemical oxygen demand, 24.0 parts per million, a decrease of 5.1 parts, as compared with 1936. These results indicate that the operation of the secondary settling tanks has continued with the usual efficiency.

Sludge Disposal

Concentration of secondary tank sludge was practiced during the open bed drying season with continued success. This feature of plant operation, installed in 1935, has greatly facilitated drying of the solids in the secondary tank sludge. The dried sludge was removed from the beds using welfare labor and the plant truck.

Use of temporary and welfare help enabled the Department to clean the dried sludge from fourteen of the forty-five one-acre beds. 10,180 cubic yards of sludge were removed at a cost of $8,441.97, an average cost per cubic yard of 82.9 cents. No supervision or foreman charges are included.

During W.P.A. work of the past three years, the Barber Greene loader could not be used. Experience of 1937 demonstrated that dried Imhoff tank sludge from heavily dosed drying beds cannot be removed as economically with the loader as by forking. The large pieces of sludge would not enter the buckets.

The cost data indicate that sludge removal should be finished by December 1 of each year; that as soon as the sludge becomes frozen, the cost for removal rapidly advances from 75 cents to about $1.20 per cu. yd.

Sludge removal has been returned to the Department as a part of its sewage treatment plant operation; therefore, it appears that provision for removal of the sludge production of a year should be made to the extent of about $15,000, to cover the cost of removal of about 20,000 cubic yards of dried sludge, between May 1 and December 1 of each year.

Total Purification of Sewage

The percentage removals do not vary a great deal from previous results in spite of the weaker sewage entering the plant. The decreased removal of free ammonia nitrogen is readily explained by the winter pooling and the irregular filter operation during the last seven months of the year.

Percentage removal figures are of interest but their value can be determined only when considering all conditions. The sewage was not so strong as in 1936 and we have a better effluent in 1937 than in 1936. Such a result indicates continued efficiency of plant operation.

Stability tests of Blackstone River water collected below the Plant, once each week, have been perfectly stable with one exception; August 17, 1937, 90 per cent.

Cost of Sewage Treatment

The cost of sewage treatment is summarized as follows:

	Total	Per Million Gallons
Grit Chambers	$ 653.52	$0.08
Screen	4,271.34	0.40
Imhoff Tanks	9,215.28	1.13
Trickling Filters	11,823.60	1.45
Secondary Tanks	6,726.27	0.82
Sludge Disposal	8,806.89	1.08
Laboratory	5,814.58	0.71
	$46,311.48	$5.67
Real Estate	215.48	
	$46,526.96	

The expenditure of $46,311.48 represents a cost of $5.67 per million gallons of sewage treated. The cost per capita served was approximately 24.4 cents for the year.

Owing to expense incurred in connection with federal projects and inadequate funds for removal of dried sludge from the drying beds, the cost of plant operation for 1937 is not a representative figure. The greatest discrepancy from normal figures is "Sludge Disposal," where about $3,600 represents pumping costs and $5,200 represents sludge removal expense. As explained in "Sludge Disposal," only a part of the sludge accumulation was removed; welfare labor was used to a considerable extent, an expense which was included in sludge removal, but which does not appear in "Sludge Disposal" in the above

TABLE I.—*Sewage Flow and Settling Period 1937*

1937	Million Gallons Daily			Settling Period Hrs.
	Average	Maximum	Minimum	
January	29.91	42.82	21.17	2.0
February	22.90	34.78	17.19	2.5
March	23.92	44.85	16.28	2.4
April	26.62	44.67	16.59	2.2
May	23.26	30.65	17.80	2.4
June	20.99	35.29	15.79	2.7
July	18.03	26.77	13.41	3.2
August	17.98	28.83	12.56	3.2
September	17.92	34.88	13.38	3.2
October	17.59	37.37	11.57	3.3
November	24.44	58.23	13.14	2.5
December	25.19	44.15	18.46	2.3
Avg.	22.39	58.23	11.57	2.7

TABLE II.—*Daily Analysis of Imhoff Tank, Trickling Filter and Settling Tank Influents and Effluents*

1937	Suspended Solids						Biochemical Oxygen Demand					
	P.P.M.				Per Cent Removal		P.P.M. 5 days 20° C.				Per Cent Removal	
	Sew.	I.T.E.	Tr.F.E.	S.T.E.	I.T.	S.T.	Sew.	I.T.E.	Tr.F.E.	S.T.E.	I.T.	Entire Plant
January	211	101	88	67	52.1	23.9	175.9	112.7	37.7	35.5	36.0	79.9
February	260	100	75	44	61.5	41.4	198.8	121.8	27.1	23.3	38.8	88.3
March	241	95	100	59	60.5	41.0	235.2	142.9	35.9	31.5	39.2	86.6
April	237	91	118	70	61.5	40.6	180.1	114.1	32.4	24.9	36.6	86.2
May	249	102	171	67	59.0	60.8	202.7	120.0	38.6	27.1	40.8	86.7
June	338	109	185	69	67.8	62.7	217.8	127.7	37.1	25.5	41.4	88.4
July	324	101	95	45	68.8	52.7	213.2	122.8	23.8	18.3	42.3	91.2
August	311	115	106	47	63.0	55.6	202.6	116.3	19.4	14.6	42.6	92.8
September	311	113	63	35	63.6	44.5	213.0	118.4	14.8	10.6	44.4	95.0
October	311	109	73	40	65.0	45.2	227.5	139.0	29.2	20.9	38.9	90.8
November	240	100	79	49	58.3	38.0	215.3	130.0	29.0	21.8	39.6	89.8
December	208	87	87	51	58.2	41.4	186.8	114.9	28.3	22.7	38.5	88.0
1937	264	100	104	55	62.1	47.1	204.0	122.9	30.7	24.0	39.7	88.3
1927	288	127			55.9		150.5	88.6	31.1	27.0	41.1	82.1
1928	275	114	120	77	58.6	35.9	152.9	98.8	20.4	18.8	35.4	87.8
1929	317	118	142	84	62.8	40.8	178.5	114.0	22.6	17.8	36.2	90.1
1930	291	117	165	86	59.8	47.9	211.6	142.5	31.0	24.4	32.6	88.5
1931	229	101	140	64	55.9	54.3	196.0	136.5	29.7	22.2	30.4	88.7
1932	219	94	143	62	57.1	56.6	211.5	140.0	34.0	22.7	33.8	88.3
1933	224	97	118	53	56.7	55.0	213.5	139.6	34.4	23.8	34.6	88.9
1934	240	95	97	55	60.4	43.3	241.0	147.6	43.9	35.8	38.7	85.2
1935	233	96	105	52	58.8	50.5	200.5	123.0	33.5	25.6	38.7	87.2
1936	256	97	92	55	62.2	40.2	207.2	129.5	36.9	29.1	37.5	86.0
1937	264	100	104	55	62.1	47.1	204.0	122.9	30.7	24.0	39.7	88.3

TABLE III.—*Analyses of Raw Sewage—Nitrogen, Oxygen Consumed, Chlorides and Iron*
Parts per Million

1937	Nitrogen				Oxygen Consumed			Chlorides	Iron as Fe		
	Free Ammonia	Organic									
		Total	Dissolved	Suspended	Total	Dissolved	Suspended		Total	Dissolved	Suspended
January	10.1	12.63	7.69	4.94	119.2	53.2	66.0	59.5	27.2	6.0	21.2
February	12.1	15.13	8.25	6.88	130.3	55.0	75.3	76.1	32.7	6.5	26.2
March	10.7	12.40	7.10	5.30	145.0	53.1	91.9	72.6	35.5	12.2	23.3
April	9.1	9.75	5.56	4.19	117.5	36.2	81.3	60.9	27.5	8.7	18.8
May	10.0	10.12	4.81	5.31	147.3	42.9	104.4	72.1	25.7	7.2	18.5
June	11.7	9.50	4.35	5.15	145.7	45.6	100.1	77.8	23.7	8.7	15.0
July	10.9	8.63	4.00	4.63	151.9	49.4	102.5	77.2	25.2	8.2	17.0
August	10.9	8.20	4.25	3.95	150.9	52.7	98.2	74.7	24.2	13.2	11.0
September	12.1	11.25	6.06	5.19	159.6	77.8	81.8	72.5	33.7	15.7	18.0
October	12.6	11.75	4.75	7.00	158.3	63.8	94.5	72.7	36.7	18.2	18.5
November	9.9	9.30	5.00	4.30	133.4	58.1	75.3	55.4	23.7	12.7	11.0
December	8.3	8.88	5.50	3.38	119.9	47.4	72.5	52.3	15.0	4.7	10.3
Average	10.6	10.72	5.74	4.98	137.8	52.1	85.7	68.7	27.3	9.7	17.6

Monthly averages of weekly analyses of sterilized daily samples composited according to daily sewage flows; irons—similar monthly composite samples from weekly composites.

TABLE IV.—*Analyses of Final Effluent—Nitrogen, Oxygen Consumed, Chlorides and Iron*
Parts per Million

1937	Nitrogen				Oxygen Consumed			Chlorides	Iron as Fe		
	Free Ammonia	Organic									
		Total	Dissolved	Suspended	Total	Dissolved	Suspended		Total	Dissolved	Suspended
January	9.9	4.28	2.31	1.97	31.7	15.8	15.9	56.5	15.3	3.0	12.3
February	12.2	3.50	1.84	1.66	25.7	14.0	11.7	70.0	11.5	1.5	10.0
March	11.5	3.48	1.59	1.89	29.6	15.6	14.0	70.6	14.9	1.2	13.7
April	9.8	3.50	1.50	2.00	29.2	12.4	16.8	65.5	16.5	0.7	15.8
May	9.8	2.78	1.12	1.66	30.6	14.1	16.5	71.1	13.2	1.2	12.0
June	8.3	2.20	1.05	1.15	31.1	14.5	16.6	70.9	11.7	1.2	10.5
July	5.7	1.91	0.91	1.00	22.9	12.0	10.9	73.0	10.2	2.2	8.0
August	5.2	1.50	0.77	0.73	18.2	11.2	7.0	72.6	10.0	2.2	7.8
September	5.9	1.50	0.96	0.54	19.6	14.2	5.4	69.8	6.5	2.0	4.5
October	6.8	2.10	1.11	0.99	22.4	13.7	8.7	70.0	6.2	0.5	5.7
November	7.3	2.30	1.19	1.11	25.3	14.1	11.2	55.6	10.7	1.7	9.0
December	7.6	2.63	1.26	1.37	33.4	17.0	16.4	51.0	9,5	1.5	8.0
Average	8.6	2.79	1.37	1.42	27.4	14.3	13.1	66.2	11.8	1.6	10.2
Entire Plant Per Cent Removal	18.9	73.9	76.2	71.5	72.9	72.5	84.7		56.8	83.5	42.0

table. Welfare labor was rated at 50 cents per hour, although supplied to the Department for transportation cost; this was necessary in order to ascertain the cost of sludge removal.

In "Sludge Disposal," an estimate for yearly operation basis of sludge removal, using temporary men at 50 cents per hour, was stated as approximately $15,000, to which should be added about $3,600 to cover sludge pumping; a total of $18,600. The operating budget should be increased approximately $15,000, compared with 1937 operation costs, to successfully carry on the removal of dried sludge from the drying beds.

TABLE V.—*Trickling Filter Operation*

1937	Average Acres in Service	Million Gallons Per Acre Per Day Average	Nozzles Cleaned Per Day	Nitrogen as Nitrites and Nitrates Filter Eff. P.P.M.
January	13.47	2.03	154	1.5
February	13.68	1.63	210	1.5
March	13.68	1.68	223	1.1
April	12.08	2.01	163	0.9
May	12.53	1.75	167	1.6
June	11.97	1.65	190	2.3
July	10.99	1.58	148	3.4
August	10.51	1.61	151	3.8
September	11.78	1.48	134	3.7
October	13.08	1.29	157	3.9
November	13.04	1.68	220	2.8
December	13.04	1.86	183	2.0
1937	12.49	1.69	175	2.3
1927	12.37	1.70	150	2.2
1928	12.68	1.75	140	5.9
1929	13.65	1.46	240	6.3
1930	13.52	1.27	261	8.6
1931	13.68	1.39	254	10.7
1932	13.68	1.39	234	12.2
1933	12.28	1.54	165	9.5
1934	12.94	1.57	164	5.2
1935	12.37	1.63	213	6.7
1936	11.75	1.68	172	3.4
1937	12.49	1.69	175	2.3

TABLE VI.—*Imhoff Tank Sludge*

1937	Wet Sludge		Dry Solids Per Cent		
	Solids Per Cent	pH	Volatile Matter	Iron (Fe)	Nitrogen (N)
January	7.53	6.9	40.64	4.07	2.57
February	7.36	7.0	41.91	3.92	2.56
March	7.10	7.0	42.01	4.63	2.32
April	6.44	6.8	43.75	3.93	2.19
May	5.87	6.6	44.22	3.82	2.20
June	6.07	6.6	41.46	3.85	2.10
July	8.24	6.8	38.36	4.25	1.92
August	7.08	6.8	33.78	4.17	1.89
September	7.67	6.9	37.08	4.35	1.85
October	7.14	6.9	41.49	4.97	1.82
November	7.15	7.0	41.00	6.14	1.95
December	7.32	6.8	42.04	4.56	1.87
1937	6.82	6.9	40.80	4.38	2.11
1927	4.93		54.66	5.27	3.76
1928	6.21		49.70	4.43	3.13
1929	6.78	6.8	45.15	3.95	2.73
1930	6.35	6.8	48.80	5.19	2.63
1931	6.78	6.9	49.70	4.69	2.51
1932	6.74	6.8	48.65	4.46	2.38
1933	6.87	6.8	49.80	3.90	2.75
1934	6.18	6.8	48.70	4.09	2.77
1935	4.63	6.8	52.65	4.41	3.10
1936	6.60	6.9	43.30	4.07	2.71
1937	6.82	6.9	40.80	4.38	2.11

Acknowledgment.—In the article, "Experiences with Paints at the Marina Sewage Pumping Plant" by Joseph Corrao, Superintendent of Pumping Plants, San Francisco, California, published in *This Journal* on page 899 of the September, 1938, issue, some of the discussion was taken from an unpublished manual of the Sanitary District of Chicago prepared by W. T. McClenahan, Senior Civil Engineer.

The author wishes to acknowledge this source of material, which was used to supplement the description of experiences with paints at the Marina plant.

Correction.—The paper "Sewage Plant Operation at Santa Clara, California," published on page 1035 of the November, 1937, issue of *This Journal,* included a table in which the percentage of hydrogen sulfide in digester gases was reported as 6.21 per cent. Mr. A. J. Castro, Jr., author of the paper, writes that this determination is grossly in error and that the corrected result is 0.12 per cent.

Editorial

CHICAGO PROGRAM NEARS COMPLETION

The sewage treatment program of The Sanitary District of Chicago, the largest and most costly in the world to date, is nearing completion. In the spring of 1939 the final treatment plant, the Southwest Works, will be put into operation. This activated sludge plant, by far the largest in the world, will have a design capacity of 400 million gallons per day of dry-weather flow, and a maximum of 600 m.g.d.

The large-scale sewage treatment work of the Sanitary District started in 1928, when the North Side activated sludge plant was placed in operation. Prior to this date, the Calumet Imhoff plant had been in operation since 1922, treating some 60 m.g.d.; the Des Plaines River activated sludge plant, largely experimental, treating 4 m.g.d. since 1922; and three very small Imhoff tank-trickling filter plants at Morton Grove, Glenview and Northbrook.

The history of sewage disposal for Chicago logically falls into two eras; the first, or dilution era, from 1900 to 1922, and the second, or sewage treatment construction era, from 1922 to date. When the Drainage Canal was built, from 1890 to 1900, the dilution theory of sewage disposal rested largely on the dictum that 3.33 cu. ft. per second of diluting water per 1,000 population would result in satisfactory disposal by the self-purification power of running water. The Illinois statute under which The Sanitary District of Chicago was formed specified that this dilution ratio should be maintained by withdrawal of water from Lake Michigan. Accordingly a flow of 10,000 cu. ft. per second would be required when the population reached three million.

The dilution project, although now supplemented by sewage treatment, was an outstanding achievement in sanitation, because it removed sewage from Chicago's water supply, and stopped the fearsome epidemics of typhoid fever formerly prevalent. At the time it was adopted, disposal by dilution was the only practicable solution for the problem, and the dilution project still makes it possible to protect the Chicago water supply by removing treated sewage and storm overflow from Lake Michigan, despite a determined legal battle by opposing interests to force Chicago to discharge the effluents into the lake.

During the decade 1910–1920 it became apparent that dilution of raw sewage was not a satisfactory solution of the sewage disposal problem. Sewage solids were deposited for more than one hundred miles down the Illinois River, and the nuisance became intolerable, although there was no direct pollution of any downstream water supply, since all water supplies of the small cities along the stream, and even of Peoria, a city of 90,000 population, are from deep wells.

In the course of planning for sewage treatment, The Sanitary District in 1924 employed a group of 28 of the most distinguished engineers in the United States. This Engineering Board of Review studied the projects proposed by the District engineers, and indicated the cost of a comprehensive sewage treatment program and the need of diluting water even after the program was completed. Earlier, in 1922, an activated sludge plant had been recommended by a consulting board of three engineers, for the North Side of Chicago, and the North Shore to Lake County. Construction of this plant was started in 1923 and it was completed in the fall of 1928. It has since been in operation, treating an average of 205 m.g.d. in 1937.

During the years 1926 to 1930 a lawsuit, brought by neighboring states on the borders of the Great Lakes, sought to enjoin the Sanitary District from diverting any water from Lake Michigan for disposal of sewage through the

Drainage Canal. The argument was submitted that the effluents should be returned to the lake, but in the decision of the U. S. Supreme Court of April 21, 1930, it was decreed that the annual average diversion should be reduced to 1,500 cu. ft. per second after December 31, 1938, and that this would be in addition to the volume of the effluents, estimated now at 1,700 cu. ft. per second.

From 1930 to 1938, The Sanitary District of Chicago has been building intercepting sewers and sewage treatment works on an unprecedented scale, in order to complete the program in 1939. The total expenditure to June 1, 1938 was approximately 152 million dollars. The capacities and costs of the main projects are as follows:

Project	Average Capacity M.G.D.	Completed	Cost in Millions of Dollars
North Side	250	1928	38
West Side	470	1935	53
Calumet	136	1936	31
Southwest Side	400	1939	30

The cost includes the cost of intercepting sewers, which amounts to approximately one-half the total. The North Side, Calumet and Southwest plants are of the activated sludge type, the West Side is as yet only Imhoff tanks. However, some 200 m.g.d. of this Imhoff effluent may be treated at the Southwest plant by the activated sludge process. This will leave 270 m.g.d. of Imhoff effluent, to be discharged with about 1,000 m.g.d. of activated sludge effluent. Experimental work on a large scale has been under way to determine the preferable method of treatment of the Imhoff effluent, whenever required.

During the progress of this program, many large-scale experimental plants have been built, operated and dismantled. An entirely new process of sludge disposal has been developed and many economies in design have been adopted as one plant after another was completed and operated. Large loans and grants from the PWA made it possible to continue construction during the depression era.

The results of sewage treatment have been measured by an extensive analytical survey of the Illinois River that has been maintained since 1925. Operation of the present activated sludge plants has proved very gratifying, with production of excellent effluents and no difficulty with bulking of sludge.

The completion of the sewage treatment program will round out the second era in the history of the Sanitary District. The third era in its history will start in 1939.

F. W. M.

Index and Anniversary Book

A few reprints of the Nine Year Index have been made. They may be obtained from Mr. Buffum for 65 cents per copy.

The Anniversary Book will be mailed about January tenth. The cost is $2.50 to members of the Federation, $3.50 to others. Send orders to Mr. Buffum.

F. W. M.

Proceedings of Local Associations

CALIFORNIA SEWAGE WORKS ASSOCIATION

Eleventh Annual Convention

Santa Barbara, September 6–7, 1938

The Eleventh Annual Convention of the California Sewage Works Association was held in Santa Barbara, California, Sept. 6–7, 1938, jointly with the League of California Municipalities.

The initial session of the convention was called to order at 9:15 A.M. in the Supervisors' Chamber of the Santa Barbara County Court House by President R. F. Goudey. Committee reports were heard, which indicated that the Association had completed a very active year. Under new business the President was authorized to appoint two committees to report at the Spring Conference, one on "Revision of Constitution and By-Laws" and the other on "Manual for Sewage Treatment."

Three papers constituting a symposium on pumps, upon which there was considerable discussion, consumed the balance of the morning session. Mr. W. M. Beadle's paper "Pumps in Sewage Works Practice" was read by Mr. Harold K. Palmer. Mr. Joseph Corrao's paper "Items to be Considered in Selecting a Pump" was read by the Secretary. The third paper "Packings for Pump Bearings" was read by the author, Mr. Bard Livingstone.

Luncheon was arranged in the typically Spanish El Paseo. Mr. Adolph Postel, Chairman Board of Harbor Commissions, gave a short address on the "Santa Barbara Harbor Problems."

The meeting reconvened in the Supervisors' Chamber at 2:00 P.M. The first paper of the session "Remodeling Old Plants to Increase Efficiency" by Mr. Jud Harmon was read by the Secretary. Mr. C. C. Kennedy read a prepared discussion and the Secretary read a discussion prepared by Mr. F. S. Currie. In addition to indicating the benefits to be obtained by the remodeling of a plant these papers revealed many difficulties frequently encountered in so doing.

The experiences of "Conditioning and Sale of Sludge for Fertilizer" at Pasadena, discussed in a paper by Mr. William A. Allen, superintendent of the disposal plant, brought out interesting facts concerning the revenue to be expected from sludge when in a vicinity where there is a demand for this type of fertilizer.

The third paper of the afternoon "Control of Chlorination" by Mr. A. Carl Beyer while presenting present problems went into the future to predict changes soon to take place in the field of chlorination.

Seven o'clock brought the delegates and their guests again to the

El Paseo for the annual banquet. The Hon. Alfred W. Robinson, Assemblyman, spoke all too briefly upon the subject of "Water Conservation in Santa Barbara County" preferring to let the Spanish Senoritas and Caballeros carry on with their songs and dances.

The Wednesday morning, September 7, session was held in the Chamber of Commerce Auditorium jointly with the Engineers Section of the League of California Municipalities. Some one said the program looked like an attorneys' meeting but actually this was not the case. Mr. A. Schapp, San Francisco patent attorney, in presenting his paper "Patents in the Design of Sewage Treatment Works" ably explained many of the legal difficulties and how they may be met by the engineer in the design of sewage plants. Mr. Homer Buckley, Assistant City Attorney of Oakland, in presenting his paper "Legal Aspects of Sewer Rental Laws and Connections from Outside to City Sewer Systems" reviewed the legal history of sewer rental laws in California and enlarged upon the subject of connections from outside to city sewer systems discussed at San Jose last September.

The final paper of the session "Disposal of Non-Polluted Waters from Cooling Systems" by Mr. Jean L. Vincenz, brought a new problem before those interested in sewage disposal, in the West. It was predicted that this problem will not be confined to the warmer climates but will gradually become more or less universal.

The usual caravan took place on the afternoon of September 7, 1938, and while short in miles of travel was nevertheless long in interest. At Ojai the caravan was met by a reception party of the Junior Chamber of Commerce and was escorted to the sewage treatment plant, an outstanding example of what can be done by the remodeling of an old plant. When returning to the cars for the trip to Ventura each car seat was found to contain a dozen large juicy Ojai oranges.

At Ventura a screening plant and new ocean outfall were inspected. The new outfall replaced the one destroyed by storms. The last plant inspected was that at Camarillo State Hospital, a biofiltration plant and new innovation in sewage treatment.

At the several sessions a count revealed the attendance to be one hundred or more. The caravan was enjoyed by approximately forty-five members.

The following officers were unanimously elected: *President,* Alexander Bell, Western Sales Manager Wallace and Tiernan Co., San Francisco; *First Vice-President,* H. G. Smith, Engineer of Sewer Design, Los Angeles; *Second Vice-President,* Harold F. Gray, Consulting Sanitary Engineer, Berkeley; *Secretary-Treasurer,* R. R. Ribal, Oakland; *Director* (5 years), Carl F. Tennant, Superintendent Plant Operation, Los Angeles County Sanitation Districts; *Board of Control Member,* A. Carl Beyer, District Manager Wallace and Tiernan Co., San Francisco.

R. R. RIBAL, *Secretary.*

OHIO CONFERENCE ON SEWAGE TREATMENT

Twelfth Annual Conference

Columbus, Ohio, September 29–30, 1938

The Twelfth Annual Ohio Conference on Sewage Treatment was held at the Ft. Hayes Hotel, Columbus, Ohio, on September 29–30, 1938. The registered attendance was 130; however, certain functions drew an attendance of 175 or more.

The Ohio Conference on Sewage Treatment followed the Ohio Conference on Water Purification, each devoting two full days to business and technical sessions, and each maintaining identity as an independent organization. Holding the two conferences at the same place and on successive days of the same week enabled those operators interested in both water and sewage treatment to attend the meetings of both organizations for the minimum expense.

The new officers elected were: J. J. Wirts, Cleveland, *Chairman*; F. E. Harroun, Akron, *Vice-Chairman*; Ben H. Barton, Findlay, *Treasurer*; and A. E. Hess, Alliance, *Member of Executive Committee*. The constitution of the organization provides that the secretary be a representative of the State Department of Health and that he be appointed by the chief engineer of the department.

The Conference formally opened with the first session at 10:30 A.M. on the first day. A short business session was immediately followed by a résumé by T. C. Schaetzle, Akron, a member of the examining board for certification and classification of water and sewage plant operators, of the activities of the board to date and of the progress which is being made to perfect plans for examining applicants for certification. It was interesting to note that under the so-called "Grandfather Clause" the board acted upon about 670 applicants. It granted certificates to approximately 370 water plant operators and approximately 200 sewage treatment plant operators in the four classifications of A, B, C and D as established by the Director of Health in "Rules Governing Certification and Classification of Operators."

The technical papers offered covered subjects of current interest to both operating personnel and to the sanitary engineering profession generally. They included the following:

"A Symposium of Five Year Sludge Digestion Studies in Cleveland" by J. J. Wirts, Cleveland.

"Experiences with Mechanical Filtration of Sludge" by F. L. Rollins, Barberton; W. D. Sheets, Columbus; and Chas. F. Hauck, Cleveland.

"Activated Sludge Bulking—Some Considerations as to Causes and Corrective Measures" by L. H. Enslow, Editor, *Water Works and Sewerage*, New York City, N. Y.

"Gas Engine Operation at Toledo" by A. H. Niles, Toledo.

"Aero-Chlorination: A Development for Grease Removal" by Harry A. Faber, Chlorine Institute, New York City, N. Y.

"Report of Research Committee on Sewage Filtration" by M. W. Tatlock, Dayton, committee chairman.

In an effort to encourage the participation of operators of small plants in the conference, several were called upon for discussions of their plants or of some particular study which they have conducted. These included:

"Five Year Operating Program at Ravenna Sewage Treatment Plant" by Hubert Hanson, Ravenna.
"Measuring pH of Sewage Sludge" by C. E. Britt, Bowling Green.
"One-man Operated Sewage Plant" by John Wahmhoff, Delphos.

Group discussions continued to be a popular feature of the program. For this purpose the following topics were offered: "Administration of Sewage Works," "Activated Sludge Treatment," "Sedimentation and Sludge Digestion," and "Sewage Filtration." These group meetings, or "round-tables" were held during the afternoon of the first day. At a conference breakfast the following morning the group leaders or their representatives summarized the respective discussions and an opportunity was given for limited general discussions of questions raised.

The annual conference dinner was well attended. The dinner speaker was S. D. Fendley, Industrial Control Specialist, General Electric Company, Cincinnati, Ohio. His subject "Electrons at Work" was ably demonstrated, was most educational, and, offered, without doubt, a welcome diversion from the "shop" topic of sewage treatment.

A very successful luncheon, furnished by the Jeffrey Manufacturing Company, Columbus, was held at the Columbus sewage treatment plant on the second day of the conference. The luncheon was served in the operating gallery of the aeration units and from general expression was thoroughly enjoyed by all. Following the luncheon, R. A. Allton gave a brief description of the Columbus sewage treatment plant and the remainder of the afternoon was utilized for the inspection of it.

On publication, a copy of the 1938 Report, Ohio Conference on Sewage Treatment, will be furnished each registrant. Due to the fact that it has become necessary to finance the publication of these reports from conference funds, copies may be obtained for a nominal charge by persons not having registered at the conference. Announcement will be made when the current report is ready for distribution.

BRUCE M. MCDILL, *Secretary*

NEW YORK STATE AND NEW ENGLAND SEWAGE WORKS ASSOCIATIONS

Second Joint Meeting

Hartford, Connecticut, October 6–8, 1938

On October 6, 7, and 8 the New York State and New England Sewage Works Associations held their second joint meeting, this time at the Hotel Bond, Hartford, Connecticut. Two hundred and eighty-two members and guests, including fifty ladies, attended the various sessions of the meeting.

The display of sewage plant equipment presented by manufacturers of such products was an important part of the meeting. These exhibits were attractively arranged in booths especially constructed around the walls of the ballroom where the technical sessions and other program activities were held. Those in attendance found the inspection of these exhibits most enjoyable as well as profitable.

The technical session on Friday morning, October 7, was called to order by Mr. John H. Brooks, President of the New England Sewage Works Association, who welcomed the New York State Sewage Works Association to the joint meeting and introduced Mr. Fred J. Biele, President of the New York State Association.

Mr. Biele then presented as the first speaker, Mr. A. F. Dappert of the New York State Department of Health, who gave a most interesting and detailed report on the recent law enacted in that state establishing requirements relative to qualifications of sewage treatment plant operators. Mr. Dappert's paper was discussed by Mr. W. J. Scott of the Connecticut State Department of Health who has had some years of experience in the administration of similar requirements.

The second paper of the technical session was presented by Mr. C. T. Butterfield, Principal Bacteriologist, United States Public Health Service, who discussed his observations on the effect of variations in the initial numbers of bacteria and of the dispersion of sludge flocs on the course of oxidation of organic material. The discussion of Mr. Butterfield's paper was opened by Mr. F. W. Gilcreas of the New York State Department of Health and many other members of the Associations contributed to the discussion and requested additional information from Mr. Butterfield.

Mr. L. W. Van Kleeck of the Connecticut State Department of Health presented the third and final paper of the Friday morning session, discussing his experiences with vacuum filtration of sludge. Mr. Van Kleeck presented a wealth of information based upon his investigation of this important subject.

The two Associations then adjourned for luncheon, the New York State Association conducting its luncheon and business meeting in one room and the New England Association in another.

Since this was the annual meeting of the New England Association, President Brooks, who presided at the business meeting, called for a

report of the Nominating Committee previously appointed. As a result of the balloting, the following officers were declared elected for the ensuing year:

President—F. W. Gilcreas, Albany
Vice-President—A. D. Weston, Boston
Secretary-Treasurer—L. W. Van Kleeck, Hartford
Directors—W. P. Petrie, Norwalk, and W. J. Shea, Providence

At the business meeting of the New York State Association, it was announced that the annual meeting of this Association would be held on January 19, 20, and 21, 1939.

Following the luncheon, two concurrent symposia were held, one dealing with the "Care and Operation of Mechanical Sewage Plant Equipment" under the leadership of Mr. Van Kleeck, and the second dealing with "Public Relations and Public Service" under the leadership of Mr. Morris M. Cohn, Editor of *Municipal Sanitation* and Sanitary Engineer of the city of Schenectady. The various papers presented at these symposia were most interesting and valuable and the successful adherence to a definite time schedule made it possible for those in attendance to go from one symposium to the other in order to hear a paper of particular interest.

Friday evening, at the Hotel Bond, was devoted to the usual banquet of the Associations. In the absence of Mayor Spellacy of Hartford, Alderman Smith of that city spoke briefly and welcomed the Associations to the city. A musical entertainment by the Hi-Boys, well-known troop of radio entertainers, followed the dinner, and dancing was enjoyed until midnight.

Entertainment was provided for the ladies who attended the meeting with luncheon on Friday at the Hotel Bond followed by a bus tour of inspection of Hartford and its environs, including the plant of the Fuller Brush Manufacturing Company. The ladies attended the banquet on Friday evening and the dancing following. Many of them also accompanied the inspection tours to the Hartford and New Britain sewage treatment plants.

On Saturday morning sharply at 8:15, the Associations assembled for a sunrise breakfast. Resolutions were adopted, congratulating the manufacturers on their splendid, instructive exhibits of sewerage equipment and thanking the various local organizations for their hearty co-operation in making this second joint meeting of these two Associations such a success.

Mr. W. A. D. Wurts, Assistant City Engineer of Hartford, then presented a very interesting description of the Hartford metropolitan sewage treatment plant and explained in detail the precautions taken by the staff of the plant and of the city engineer's office to prevent serious damage to the plant and its equipment during the recent flood conditions.

At 10:00 A.M. the members and guests left in private automobiles for the Hartford sewage treatment plant where guides conducted

groups through the plant. Unfortunately, because of flooding during the recent high water stage of the Connecticut River, it was not possible to operate the plant and, therefore, the routine operation could not be observed, but the various treatment units were open for inspection.

At the conclusion of the inspection of the Hartford treatment plant, automobiles proceeded to New Britain for luncheon at the Hotel Burritt. Here the Associations were entertained as guests of the Guggenheim Brothers, Inc., New York City. Following luncheon, the sewage treatment plant of New Britain, which employs chemical treatment in accordance with the Guggenheim process, was visited. Everyone enjoyed the opportunity of observing and inspecting the operation of this unique plant.

At the conclusion of the inspection of the New Britain sewage treatment plant, the second joint meeting of the New York State and New England Sewage Works Associations was concluded.

F. W. Gilcreas, *Secretary*

PACIFIC NORTHWEST SECTION OF SEWAGE WORKS OPERATORS

First Short School

Seattle, Washington, October 13–15, 1938

The first short school of the Northwest Section of Water Works and Sewage Works Operators was held in Seattle, at the University of Washington, under the able leadership of the Department of Health, the Civil Engineering Department of the University of Washington, and the Pacific Northwest Section of the American Water Works Association and the Pacific Northwest Sewage Works Association.

There was a total of eighty-six men registered and out of that group fifty-six received certificates of attendance. About thirty were expected to be there so the results were well appreciated by the people responsible for the program.

The program, insofar as sewage treatment problems are concerned, was as follows:

October 13. "Purpose and Aims of the School" by Roy M. Harris. A lecture on "'Practical Chemistry and Bacteriology" by Paul Seufer. A lecture and demonstration of laboratory tests by Prof. R. B. Van Horn.

October 14. "Rules and Laws Governing Water and Sewage" by Roy M. Harris. "Fundamentals of Sewage Treatment" by Prof. R. G. Tyler. "Composition and Behavior of Sewage" by Roy M. Harris. "Digestion and Disposal of Sewage Solids" by R. B. Thompson. A lecture and demonstration on pumping equipment by Prof. C. W. Harris. In the evening a round table was held in which time Max S. Campbell gave a discussion of cross connections, illustrated with slides.

October 15. Paul Seufer discussed sewage plant operation dealing with such topics as flow measurement, grit chambers, screens, septic tanks, Imhoff tanks, sedimentation units, digesters, drying beds, and records.

Certificates were awarded at the luncheon, at which time the school was officially closed.

FRED MERRYFIELD, *Secretary*

CENTRAL STATES SEWAGE WORKS ASSOCIATION

Eleventh Annual Meeting

Neenah, Wisconsin, October 13–14, 1938

The Eleventh Annual Meeting of the Central States Sewage Works Association was called to order at Valley Inn, Neenah, Wisconsin, on October 13, 1938. Total registration was 149 members and guests, of which 22 were ladies.

Opening Session, October 13.—In the absence of President Dawson, who was delayed enroute to the meeting, Vice President Schroepfer presided.

Mr. W. H. Clifford, President of the Neenah-Menasha Sewerage Commission, presented the address of welcome as scheduled in the program, after which the following committees were appointed to function during the meeting:

Auditing Committee: E. J. Beatty, Wisconsin, *Chairman*; C. V. Erickson, Illinois; C. M. Leonard, Indiana.

Resolutions Committee: A. J. Duvall, Minnesota, *Chairman*; E. E. Smith, Illinois; D. A. Poole, Indiana; L. F. Warrick, Wisconsin.

The report of the Secretary-Treasurer was read and accepted subject to the approval of the Auditing Committee.

Mr. C. L. Gordon of the Dorr Company presented the paper prepared by D. C. Reybold entitled "Sludge Drying and Incineration."

The first paper of the afternoon session was by Clair N. Sawyer and M. Starr Nichols, entitled "Activated Sludge Oxidation. I. Effect of Sludge Concentration and Temperature on Oxygen Utilization." This was followed by "The Measurement of Biologic Oxidation" by Don E. Bloodgood. C. C. Ruchhoft presented the paper entitled, "Total Purification, Oxidation, Absorption and Synthesis of Nutrient Substrates by Activated Sludge," by C. C. Ruchhoft, C. T. Butterfield, P. D. McNamee and Elsie Wattie.

Following this paper the meeting adjourned to inspect the Neenah-Menash sewage disposal plant.

In the evening, a very interesting talk was given by Frank Bachmann on "A Trip to India." Mr. Bachmann's talk was illustrated with colored slides and movies.

October 14.—The Operators' Breakfast, led by C. C. Larson, was

exceedingly successful, and this feature will undoubtedly be incorporated in future programs.

The papers presented on Friday morning were as follows:

"Digestion Experiments at Aurora, Illinois" by Walter A. Sperry; "The Concentration of Activated Sludge with a Continuous Feed Centrifuge" by L. S. Kraus and J. R. Longley; and "Chemical Treatment at Waukegan, Illinois" by Gladys Swope.

Luncheon followed, at which time President Dawson presided over the business meeting. The results of the "Gadget" balloting gave the first prize to Don E. Bloodgood for his "Aeration Machine," second prize to Don E. Bloodgood for his "Pump Timer" and third prize to C. O. Baetz for his "Ball Valve Remover." Dr. Mohlman, winner of the 1936 award for the best contribution to that program, presented a bronze plaque to the Association to be awarded each year to the winner of the gadget competition and Mr. Bloodgood was the recipient of this for the year 1938–39. The competition was especially keen at this meeting, eleven fine devices being entered, all of them receiving good consideration in the balloting.

The auditing committee recommended that the report of the Secretary-Treasurer be accepted and placed on file. Upon motion by Beatty and second by Babbitt, this was so ordered.

The Awards Committee recommended that the 1937 award be presented to W. D. Hatfield for his paper, "The Viscosity or Pseudo Plastic Properties of Sewage Sludge," read at the St. Paul meeting. The report was accepted and the award ordered.

The Resolutions Committee offered resolutions regarding: (1) the co-operation and aid rendered by P.W.A. in the construction of sewerage works, (2) a similar one regarding W.P.A. aid, (3) the death of Jos. J. Bohman, (4) the death of Harry E. Wilson, (5) appreciation of the fine work of Dr. F. W. Mohlman as Editor of the *Sewage Works Journal* and (6) appreciation of the excellent hospitality and arrangements made for the current annual meeting. These resolutions were adopted and the Secretary ordered to send them as presented.

The following officers were recommended by the Nominating Committee and upon motion by Babbitt and second by Lamb, the Secretary was ordered to cast a unanimous ballot for their election:

President.—G. J. Schroepfer, St. Paul, Minnesota. *First Vice Pres.*—B. A. Poole, Indianapolis, Indiana. *Second Vice Pres.*—C. C. Larson, Springfield, Illinois. *Third Vice Pres.*—George Martin, Green Bay, Wisconsin. *Secretary-Treasurer.*—W. H. Wisely, Springfield, Illinois. *Representative to Federation.*—J. L. Ferebee, Milwaukee, Wisconsin.

Dr. F. W. Mohlman extended an invitation for the next meeting to be held at Chicago, which was received for consideration by the Executive Committee.

Following a brief address by President-Elect Schroepfer, the meeting was ordered adjourned.

W. H. Wisely, *Secretary*

Reviews and Abstracts

H. W. STREETER

WEST RIDING OF YORKSHIRE RIVERS BOARD

Forty-Third Report
Year Ending March 31, 1938

BY JOHN GARNER, *Chief Inspector*

The West Riding District includes 440 sewage works and about 700 trade premises from which effluents are discharged to streams. The Rivers Board maintains supervisory authority over the operation of these plants, advises towns concerning extension of works, brings legal proceedings against urban districts or industries, investigates streams, and carries on laboratory research. The staff numbers 24, including 5 assistant chemists. During the year 2,031 analyses were made, comprising 1,291 samples of sewage, 423 of trade refuse, 202 of stream water and 115 miscellaneous. Copies of analyses are sent to the sewage works and inspections are made where necessary, particularly of streams.

Loans for sewerage and sewage treatment amounted to £205,736 in the year, relating to only 20 authorities. This was somewhat less than in preceding years, but there is prospect of greater activity after completion of the review of county districts under the Local Government Act of 1929. This may lead to desirable centralization of sewage treatment in certain districts.

FIG. 1.—Mr. Wontner-Smith's office at the Bradford Works.

In the last annual report reference was made at some length to the serious pollution that may arise from the discharge of stormwater sewage into streams which have become abnormally low after periods of drouth. The 1938 report again emphasizes the need for larger capacities of stormwater tanks.

Small works are predominant in the West Riding. "The difficulties met in selecting a method of purification and designing small sewage works are often as complex as

those relating to large works. Therefore, however small a scheme may be, it is always advisable to entrust the work to an experienced person. Choice of site, avoidance of nuisance from odours and flies, sludge disposal and possibility of future extensions are all factors which should be taken into account. It is particularly important to ascertain correctly the variations of strength of sewage, volume per day, and duration and rate of maximum flow, as these may vary widely on different days of the week in the case of small installations. A high standard of purification should be aimed at, as most small works discharge their effluents into small streams."

Larger works which require extensions are at York, where an application has been made to the Ministry of Health for authority to borrow £180,000 for extensions of the stormwater tanks, filters, sludge tanks and drying beds; the Shipley plant, below Bradford, £75,000; and at Halifax, £80,000 for extensions.

At the Esholt Works (Fig. 1) of the Bradford Corporation, the filter-pressing and grease recovery plant have been extended and a plant is being installed for the investigation and production of by-products from the recovered grease.

FIG. 2.—Trickling filters at the Leeds Knostrop Works. (Mr. Garner being shown a modified form of the Hartley distributor.)

The effluent from the Leeds Knostrop Works (Fig. 2) has continued satisfactory during the year. The sludge-pressing plant has been enlarged and is now the largest and best-designed of its particular type in England; it has fully justified itself as being the most efficient and economical method of sludge disposal under the conditions existing at Leeds. The limed sludge is pressed and loaded into dump cars, which are shunted up an incline to a tip for loading trucks (Fig. 3). All of the filter cake is taken away to be used on land.

The main sewage works of the Sheffield Corporation at Wincobank have been enlarged by four additional bio-aeration units, at a cost of £56,290. With these, there will be a total of 25 units, having a capacity of 17,350,000 Imp. gallons. This will provide an aeration period of somewhat less than 24 hours for the dry-weather flow and will permit up to three times the dry-weather flow being treated in wet weather.

Many smaller works in the various river catchment areas are being extended or modified. Industrial wastes frequently complicate operation, as at Saddleworth, where soapy scouring liquors from the manufacture of flannel goods constitute a large pro-

portion of the sewage flow. Acid is used for coagulation, as at Bradford, and the council has entered into an agreement with a firm of grease merchants, whereby the latter have undertaken for a period of 21 years to contribute a portion of the cost of acid treatment, receiving in return the whole of the sludge, which they expect to treat for recovery of grease.

Industrial wastes are of great variety, mainly from textile works, coal, coke or gas plants, chemical works and the Poppleton beet sugar factory, often discussed in previ-

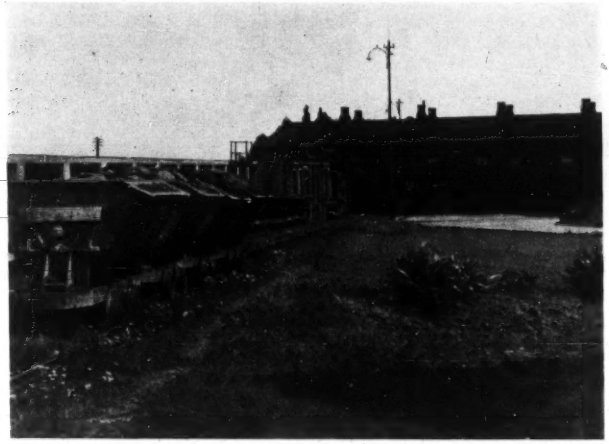

FIG. 3.—Sludge-cake tip at Leeds.

ous reports of the West Riding Board. Clarification of coal-washing wastes is improved by adding flocculants, usually starch and lime, starch and caustic soda, or alkalies plus tannin, glue or casein.

The report concludes with tables of analyses of various river waters, sewages and effluents. The net expenditure of the Rivers Board was £12,591 for the year.

(*Note.*—The photographs were taken by the abstractor during a very pleasant day spent with Mr. Garner last July.)

F. W. MOHLMAN

SOME FACTORS AFFECTING THE DESIGN OF SEWAGE DISPOSAL WORKS

BY JOHN HURLEY

Works Manager, Wolverhampton

Presented at a Sessional Meeting of the Institution of Sanitary Engineers, London, May 6, 1938

Excerpts in *The Surveyor*, **93**, 657 (1938)

Preliminary considerations in the design of sewage works require information concerning the dry weather flow of sewage and stream. Domestic sewage flow in England averages approximately 20 Imp. gallons per capita per day. Stream flows should be gauged.

The degree of treatment for inland cities is defined by the standards of effluents of the Royal Commission, also dilution ratios are specified for various types of treatment. Use of the stream water may also influence the type of design. For example, manufacturers using the river water for cooling purposes object to corrosive constituents or profuse vegetable growths; if used in plant processes, iron is usually objectionable. Wastes such as iron pickle liquors must therefore be watched carefully to prevent discharge of acid or iron to the stream. Important fisheries deserve consideration and usually require thorough purification of sewage.

Trade wastes should be investigated before the sewage treatment works is designed. Flows should be measured, samples taken and agreements made with the manufacturer. This agreement should cover, say, 10 years, and should fix the degree of preliminary treatment at the trade premises, cover regulation of the rate of flow, specify the maximum temperature of the waste, provide for access to the firm's works, and include the rate of payments to be made by the firm, with recourse to arbitration in case of disputes. "It is reasonable that the manufacturer should contribute to the cost of treating trade effluent; in determining this contribution, regard must be paid to the strength and volume of the trade effluent and to the degree of purification which is necessary before the effluent can be discharged from the sewage works."

The sewage works site must be selected with consideration of space for sludge disposal, isolation if odors or filter flies are expected, with no reliance on the "prevailing winds" to remove them.

Bar screens are usually provided, with openings as narrow as ½ to ¾ inch if screenings are macerated and returned to the sewage, otherwise with openings of 1½ to 2 inches. In small works, without continuous attendance, there may be advantage in eliminating screens on sewage and using ¾ inch screens on the sludge, since there are always men on the job when sludge is being pumped. Fine screens are not used in conjunction with more complete treatment, as settling tanks are considered more effective.

Grit chambers should have fairly high inlet and outlet velocities, the former to prevent formation of a bank of heavy grit at the inlet and the latter to carry forward organic matter which may show a tendency to accumulate near the outlet.

Sedimentation tanks with mechanical sludge removal can be designed with one-half the detention period of hand-cleaned tanks, but the longer period has the advantage of levelling out variations in strength of sewage or dissipating surges of industrial wastes. Long periods, however, increase septicity and allow cooling of the sewage, a disadvantage before biological treatment. An effluent containing 150 p.p.m. of suspended solids can with suitable precautions be treated in activated sludge plants or on coarse filters, but should not be fed directly to filters containing stone of less than one-inch gauge.

Biological treatment is in general confined to land treatment, activated sludge and filters. Land treatment is no longer installed for large cities. Activated sludge needs little space (except for the Haworth system), there is no nuisance from smell or flies, the first cost is usually lower than for filters, and there is little loss of head. Sludge can be returned to the preliminary tank, thus simplifying disposal.

Trickling filters are undergoing a revival, which may result in extension of their use. They have been known to require little attention, to be hardy in operation, and to require little power in operation, but are high in first cost, cover large areas, may produce odors or fly nuisances, and require considerable head. Most of these disadvantages are eliminated or minimized by the newly investigated high-rate filters of Halvorson, Jenks and Blunk, but the effluents are usually of inferior quality when rates are greatly increased. The Blunk enclosed aerated filter is being investigated at Wolverhampton. The alternating two-stage filter, found of value in treatment of milk wastes, is to be studied at Birmingham on sewage.

Sludge disposal has undergone some improvement, but more regard should be paid to the potential value of the sludge as fertilizer. If digestion be undertaken, it should be carried to completion, as incomplete or badly operated digestion can cause far more smell nuisance than the discharge of raw sewage. The prospects for development of mechanical dewatering of sludge are very promising. Such a procedure has the advantage of independence of climatic conditions, small area, and production of a market-

able fertilizer. The elimination of unsightly and noxious sludge dumps is another inducement.

(Mr. Hurley's paper has a few "pithy paragraphs" that warrant quotation. *Abstractor.*)

"In general, if a manufacturer needs a water of high quality, approaching that of of a first-class public supply, it seems reasonable to expect him to treat the river water before use. Unfortunately, this reasonable expectation is not always in conformity with the law, and although the law may be an ass it pulls a lot of weight."

"It is not fair to put on to the general ratepayers the whole cost of disposing of a manufacturer's refuse, because the manufacturer does not give them his profits."

"It should be remembered that mineral fertilizers cannot completely take the place of organic manures, any more than a man can thrive on a diet composed entirely of brandy or vitamin pills."

"It is doubtful whether a local authority should be expected to spend many thousands of pounds per annum with the sole object of coaxing a few fish into waters which they would not otherwise patronise. It is no more reasonable to expect the general ratepayer to provide anglers with their recreation than it would be to expect him to provide, say, motor cars or free drinks for people whose tastes lie in those directions."

"Through the haze of contradictory interests, the sewage works designer tries to find the ideal scheme for each particular case. Local residents, fisheries and angling clubs, ratepayers, the law of the land, riparian owners—these are a few of the interests he has to reconcile. Small wonder that he sometimes envies Noah, who had infinite dilution and no alternatives."

F. W. MOHLMAN

ANNUAL REPORT, SEWAGE PURIFICATION WORKS, GLASGOW, SCOTLAND, 1937–38

BY ALEXANDER HUNTER

General Manager

This is the report for the year ending May 31, 1938, describing the operation of the Glasgow main drainage works (serving 40,000 acres), comprising three sewage treatment works, using chemical precipitation with lime and sulfate of alumina.

At the Eastern Works (Dalmarnock) the average flow was 20 m.g.d. (U. S.), of which 41 per cent was further treated by trickling filters. 176,379 tons of sludge was pumped 6¼ miles in a 9-inch main to the Shieldhall Works at a cost of 1.3 pence (2.6 cents) per ton. The sludge was dewatered and taken to sea at a further cost of 11.5 cents per ton. The cost per million U. S. gallons of sewage in 1936–1937 and 1937–1938 was as follows:

Operation	1936–1937	1937–1938
Pumping (20 ft. 1 ft.)	$ 4.46	$ 4.82
Precipitation	8.72	9.14
Sending sludge to sea and force main	0.66	0.60
Land Charges (Shieldhall)	0.51	0.55
Water Charges (Shieldhall)	2.31	2.41
Filtration	1.10	1.23
Total	$17.76	$18.75
Cost per m.g.		
Treating on Biological Filters	$ 2.82	$ 2.96
M. G. D. Treated—		
Chemical Precipitation	12.85	11.37
Chem. Precipn. Biological Filtration	8.20	8.16

At the Dalmuir Works, the sludge is taken to sea, some 31 miles from the works, at a cost of 13.4 cents per ton.

The cost per million U. S. gallons of sewage on the total flow was as follows:

Operation	1936–1937	1937–1938
Pumping	$1.27	$1.26
Precipitation	6.05	5.91
Sludge to Sea—		
Land Charge	0.50	0.49
Water Charge	2.05	2.19
Total	$9.87	$9.85

At the Shieldhall Works, the sludge is taken to sea, with the sludge from Dalmarnock, at a cost of 11.2 cents a ton. The cost per million U. S. gallons of sewage total flow was as follows:

Operation	1936–1937	1937–1938
Pumping	$1.47	$1.48
Precipitation	6.48	6.33
Sludge to Sea—		
Land Charge	0.34	0.35
Water Charge	1.53	1.73
Total	$9.82	$9.89

The operating data are summarized in Table I.

TABLE I.—*Summary of Physical Data, Glasgow, Sewage Treatment Works*

	Dalmarnock		Dalmuir		Shieldhall	
	1936–37	1937–38	1936–37	1937–38	1936–37	1937–38
Sewage, M.G.D., U.S.	21.06	19.53	45.89	46.04	38.49	40.98
Sludge						
Total, Tons	183,758	179,171	310,675	322,965	223,052	266,804
To Sea, Tons	180,848	176,379	306,232	318,817	220,449	264,407
Avg. Moisture %			88.68	90.2	89.87	89.93
Chemicals						
Lime, Gr. per Gal.		5.05		5.34		3.49
Alum, Gr. per Gal.		1.37		1.99		2.65

The analytical results are reported for the various works, with monthly or quarterly averages. For convenience, yearly averages were computed from June, 1937, to May, 1938, inclusive (Table II).

On monthly averages, the purification effected was as follows, in ranges:

Works	Per Cent Removal	
	Alb. Amm.	Ox. Absorbed
Dalmarnock Effluent	62.1–72.5	43.9–57.5
Dalmuir *	34.8–42.3	30.2–31.3
Shieldhall *	30.6–37.9	27.5–33.4

* Quarterly composites.

TABLE II.—*Operating Results, Glasgow Sewage Treatment Works*

Results in Parts per Million

Determination	Dalmarnock				Dalmuir		Shieldhall	
	Crude	Tank Eff.	Filter	Works	Crude	Effluent	Crude	Effluent
Ammonia								
Free	28.1	27.5	14.8	20.7	21.8	20.7	21.2	18.4
Alb.	8.32	4.32	1.47	2.69	5.6	3.6	5.1	3.4
Ox. Consumed—								
4 hr., 27° C.	102.1	76.8	28.1	50.7	66.9	46.3	63.3	43.8
Chlorine	118.3	123.9	123.6	118.7	66.7	63.7	80.7	76.1
Nitrites			0.15					
Nitrates			12.1					
Suspended Solids								
Total					326.7		318.8	
Mineral					119.1		146.1	
Volatile					207.6		172.7	

Experimental work is being conducted on a Simplex activated sludge unit (600,000 g.p.d.) and an enclosed aerated filter, 52 ft. diam. by 18 ft. deep (660,000 g.p.d.).

LANGDON PEARSE

ANNUAL REPORT OF THE RUHRVERBAND, ESSEN, GERMANY

BY MAX PRÜSS

Abstract, *Gesundheits Ingenieur*, **61**, 643 (October 20, 1938)

The increase of water consumption in the Ruhr District over that of the previous year amounted to 15.2 per cent. This was caused by industrial expansion, and resulted in intensified pollution of the Ruhr by industrial wastes. Industrial expansion is revealed by the rapid growth in production in the iron industry during the past years. The consumption of acids, used for pickling iron and steel, is a good index of the status of industrial activity. During the past three years the acid consumption in the district has doubled and since 1932 it has increased 250 per cent. The discharge of spent pickling liquor has become so large that during the cooler seasons of the year, the iron, particularly that which is contained in the spent pickling liquor coming from the Lenne district, cannot be retained completely in the two upper Ruhr settling basins, the Hengsteysee near Hagen and the Harkortsee near Wetter.

It has been possible to make arrangements with a large chemical works, which lately erected a new plant for the production of iron pigments for paint, to furnish it with spent iron chloride pickle which originates in the Ruhr district. This spent pickle is collected and stored in acid-proof tanks and is then transferred by rail in tank cars to the chemical plant. Up to the end of 1937 there were 2,376 metric tons of pickle liquors disposed of in this manner and thus withheld from the Ruhr. No favorable arrangement of this kind has yet been made for the utilization of spent sulfuric acid pickling liquors. With the assistance of the Reichsstelle für Wirtschaftsausbau, it was possible in the open market to dispose of certain quantities of iron sulfate salts which were reclaimed by crystallization from spent liquors. According to experiments which have been conducted up to date, it may be expected that larger quantities of iron sulfate salts will be utilized if economic assistance be forthcoming. Construction of some recovery plants has been started.

The deposition of sludge in the Ruhr lakes has increased considerably and many new sludge banks have formed in the river. The construction of a new de-sludging machine was started at the beginning of the current fiscal year; however, this plant cannot be put into operation until the summer of 1938.

The removal of aqueous vegetation from the Hengsteysee was started in June. At the Harkortsee a new type of equipment for the removal of such vegetation has been installed. It should be mentioned that pollution by oil has noticeably increased.

The clarification plant Iserlohn has been remodeled by installation of two large aerated covered trickling filters, each 22 m. in diameter and 1500 m^3 in volume.

During the fiscal year, three thorough investigations of the Ruhr have been conducted at Gelsenkirchen, with the co-operation of the Institut für Hygiene und Bakteriologie. Compared with the conditions which existed during previous investigations made at a similar level of the river, it has been found that the pollution of the Ruhr has greatly increased. The transparency of former samples free from sewage was 54 cm., but this was lowered to 7 cm. in some of the present tests, while at the mouth of the Ruhr, before it enters the Rhine, the transparency was 31 cm. The chloride content rose from 10 to 138 mg./l. The increase of the sulfate content amounted to 85.6 mg./l; it rose from 14.4 to 100 mg./l.

The hardness, which in the upper stretch of the river was 4.8° H, rose to 9.5 H at the mouth.

The water of the Oelbach showed a steady increase in phenol content, which rose from 54 to 120 mg./l. A comparison of these values with those obtained in previous years (which varied between 30 and the maximum of 65 mg./l) shows the degree of increase of industrial activities. This fact is further evidenced by the heavy increase of pollution of the river by organic matter.

The total expenditures of the Ruhrverband up to the end of 1937 amounted to 98,929,000 Rmk. Its obligations are 74,509,000 Rmk. Besides this there are bonded obligations of 11,000,000 Rmk. in circulation, so that the total debts amounted to 63,500,000 Rmk.

F. W. MOHLMAN

CONSTANT VELOCITY DETRITUS CHANNELS. RECENT DEVELOPMENTS IN DETAILS OF DESIGN

By L. B. ESCRITT

Surveyor, **94**, 383–384 (October 7, 1938)

The author contends that in many instances English grit chambers have been overdesigned in respect to necessary capacity so that offensive organic material was settled with the grit.

He then notes the development of constant velocity channels starting with a number of channels in parallel, manually thrown in and out of service with changes in flow.

A later development was the use of one or two channels with the cross-sectional area automatically proportioned to the flow by weir or flume control. One channel of this type with a rectangular cross-section in which the velocity was maintained comparatively constant by means of a specially shaped weir plate was described in *The Surveyor* of August 2, 1935, by Mr. A. Johnson.

A more recent arrangement is to construct a channel of parabolic cross-section with a "standing wave flume" at the outlet end with the invert of the flume level with the channel invert. The rate of flow through the flume can be calculated at any depth of flow and the parabolic channel section proportioned so that as the flow increases the area of the channel so increases that the velocity remains constant. By constructing two such channels, each with its own flume, they may be used either separately or in parallel without affecting the velocity.

The construction of such channels need not be expensive. The parabolic shape is very closely approximated by two radii in most cases. If at any time it is desired to increase the capacity of the channels to accommodate additional flow, it is only necessary to increase the height of the sides, maintaining the correct curvature and increase the depth of the flume.

R. S. SMITH

SLUDGE DIGESTION TANKS. METHODS AND PRINCIPLES USED IN DESIGN

By L. B. ESCRITT

Surveyor, **94**, 279–280 (Sept. 9, 1938)

Sludge digestion units are of three classes: (1) heated and stirred tanks; (2) two-stage units consisting of a heated and stirred tank followed by an unheated quiescent tank, and (3) single or double-stage unheated and unstirred tanks. A maximum degree of bacterial activity occurs at 80° F.; hence at this temperature a minimum detention period and tank capacity are required. Against this is offset the cost of heating and stirring machinery. The economic advantage of heating is particularly evident when it is intended to use the sludge gas for power and other purposes. For large installations the two-stage treatment as in (2) above is the most satisfactory. Imhoff has stated that heating is always economically sound.

Cold-digestion tanks may be concrete structures or deep lagoons, the latter being more economical. With the lagoon type of tank, excavation can be made with sides sloping at an angle that can be maintained by 9 or 12 inches of concrete.

The proportions of the tank are based on economical considerations and with regard to avoiding patches of "dead water" or useless capacity. As with settling tanks, streaming should be avoided and an even distribution of influent flow is essential. Unlike settling tanks, digestion tanks do not require steep falls in their floors. Detritus should be excluded as far as practicable. The floors should be given sufficient falls for complete emptying of tanks for repairs.

In two-stage digestion, the primary tanks may be rectangular and similar in shape and capacity to secondary tanks but it is often advantageous to construct them as circular drums, which may be readily convertible into heated and stirred tanks. Secondary tanks are usually rectangular, about 2 to 4 times as long as they are broad, and about 10 ft. average depth. Between primary and secondary tanks a difference in level of 3 to 4 ft. is necessary to give requisite hydrostatic head for drawing sludge from the former, and a similar head is required between the top water level of the secondary tanks and the sludge beds.

The capacity of heated or cold tanks may be calculated from the estimated or known

amount of sludge and the detention period necessary for satisfactory digestion at the assumed temperature. The quantity of sludge from a domestic system is stated by Imhoff as 0.5 gallon per capita per day, when the sludge contains 97.5 per cent of moisture. This quantity has agreed with conditions in England. Assuming this quantity to be normal, the amount of sludge of any moisture content may be calculated thus:

$$\text{Gal. per capita per day} = \left(\frac{\%\ \text{moisture}}{\%\ \text{solids}}\ \text{plus}\ 1 \right) \times \frac{1}{80}.$$

From this formula may be deduced the following formula giving the required digestion capacity, assuming that no water is removed during digestion:

$$\text{Cu. ft. per capita} = \left(\frac{\%\ \text{moisture}}{\%\ \text{solids}}\ \text{plus}\ 1 \right) \times \left(\frac{\text{no. days' detention}}{500} \right).$$

According to a curve given by Imhoff, the times required for digestion to the "technical limit" are ¾ of a month at 80° F. and 2 months at 60° F. Applying the Imhoff figures to this formula, curves are drawn showing the required capacities at 80° and 60° for various degrees of moisture.

For the intermediate case of two-stage digestion, heated followed by cold, the capacity required will not be much greater than for a heated single-stage system, as the advantage of the two-stage system tends to offset the fact that the second stage is without heat. The greater part of digestion and gassing takes place in the primary tank, while in the secondary tank surplus water is readily withdrawn. Where much trade waste is present in the sewage, it is usual to as much as double the normal capacity used for domestic sewage. The following figures are given as a rough guide to capacities required under different conditions:

	Cu. Ft. per Capita
1. Domestic sludge, single-stage heated, or two-stage with primary tanks heated	About 1.5
2. Sludge containing inhibitory trade waste, with single-stage heated or where primary tanks are heated; also for domestic sewage in two-stage unheated tanks	About 3.0
3. Sludge containing trade waste in unheated tanks	6 or more

It is advantageous to remove as much water as possible before passing sludge to digestion tanks, by means of thickener tanks or similar devices. The reduction in quantity of sludge may be calculated by Santo Crimp's formula:

$$W_2 = \left(\frac{100-P}{100-Q} \right) W_1,$$

where

W_1 = original weight of sludge,
W_2 = reduced weight of sludge,
P = percentage of moisture in sludge before reduction,
Q = percentage of moisture in sludge after reduction.

After the sludge has been thickened, it should be mixed with at least 20 per cent of its bulk of actively digesting sludge drawn off from some position half-way through the treatment. This may be accomplished by using two pumps driven from one shaft and having a common delivery; one of which draws from the raw sludge well and the other from below half-way down the primary digestion tank.

Sludge gas has a high calorific value. About 0.8 cu. ft. of gas per capita per day (a variable figure) is given off by domestic sludge, about 0.6 cu. ft. being given off in the primary tank. The calorific value of the gas is about 630 B.T.U. per cu. ft., and 19 cu. ft. will produce about 1 b.h.p. hour when used in a gas engine designed for the pur-

pose. Precautions to be taken include the installation of flame traps in the gas pipe system and water seals which may be blown by excessive pressure. Pressures of about 18 in. head of water are usual.

Where heated tank walls are buried in the ground, the earth gives sufficient insulation; but exposed concrete walls should be insulated with cork or other covering. The following formula gives roughly the loss of heat through concrete walls:

$$\text{B.T.U. per ft. super. per hr.} = \frac{45}{\text{inches thickness of wall}} \text{ plus 4, for walls from 6 in. to 2 ft. thick.}$$

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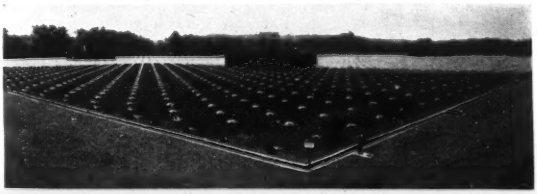

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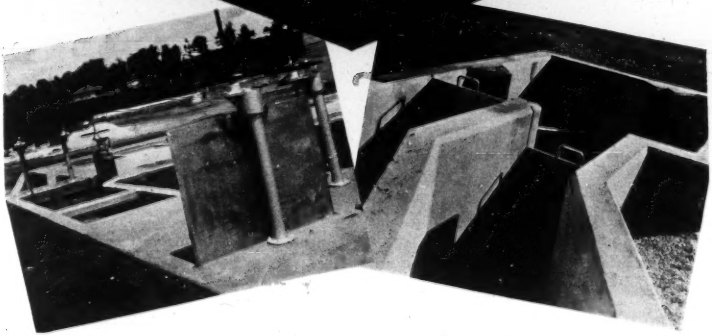

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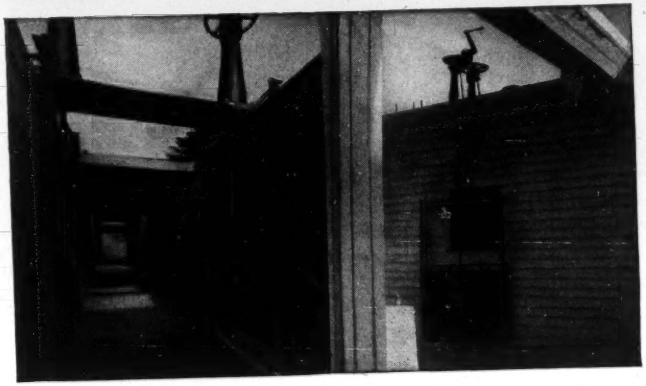

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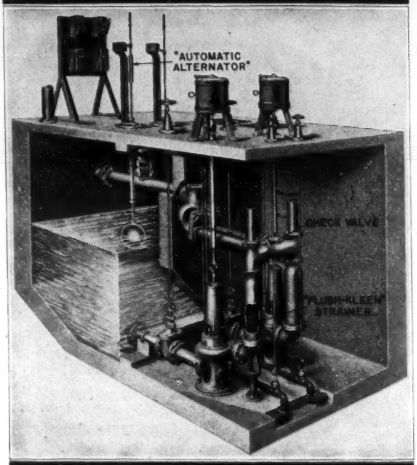

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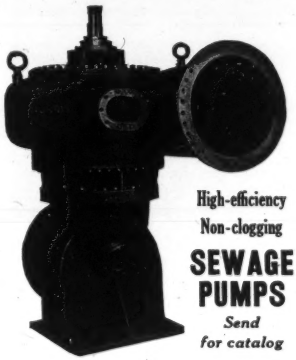

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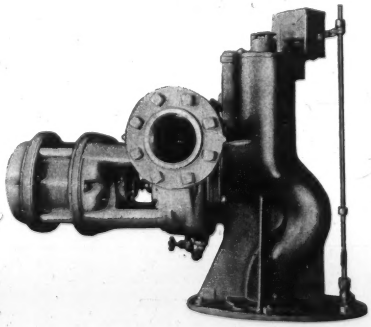

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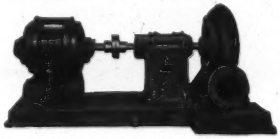

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